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ACTIVE SOLAR ENERGY SYSTEM DESIGN INSTALLATION AND  
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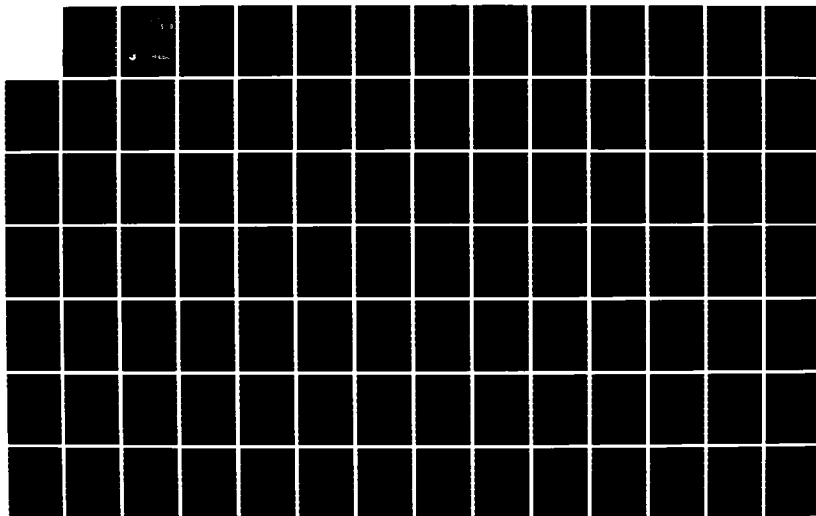
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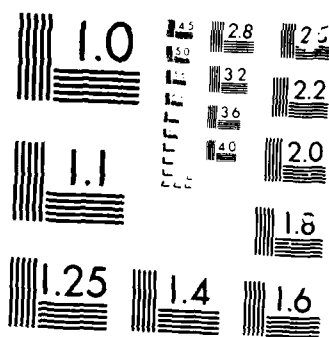
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# Active Solar Energy System Design, Installation & Maintenance Manual

S. C. DIAMOND  
J. G. AVERY  
C. WOOD

LOS ALAMOS NATIONAL LABORATORY  
SOLAR ENERGY SECTION  
ADVANCED ENGINEERING TECHNOLOGY GROUP  
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19. ABSTRACT (Continue on reverse if necessary and identify by block number) This manual provides project managers, engineers, and operations and maintenance personnel with information on designing, installing, and maintaining active solar energy systems for a variety of applications at Air Force facilities. These systems include domestic hot water, industrial process heat, space heating, space cooling, and swimming pool heating systems.				
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## PREFACE

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This report has been reviewed by the Public Affairs Office (PA) and is releasable to the National Technical Information Service (NTIS). At NTIS it will be available to the general public, including foreign nationals.

This technical report has been reviewed and is approved for publication.

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## ABBREVIATIONS

A	- ampere
A/E	- Architect/Engineer
ASHRAE	- American Society of Heating, Refrigerating and Air-Conditioning Engineers
ASME	- American Society of Mechanical Engineers
BTU	- British Thermal Unit
BTUH	- British Thermal Units per Hour
°c	- degrees centigrade
Cmin	- minimum heat exchanger capacity rate
Cmax	- maximum heat exchanger capacity rate
Cp	- specific heat of fluid
CERL	- U.S. Army Construction Engineering Research Laboratory
CPVC	- Chlorinated polyvinyl chloride
DHW	- domestic hot water
DHWR	- domestic hot water return
DHWS	- domestic hot water supply
dia	- diameter
DL	- developed length
E	- effectiveness (heat exchanger)
EPDM	- ethylene-propylene-diene-monomer
FOA	- Field Operating Agency
fps	- feet per second
ft	- feet or foot
°F	- degrees fahrenheit
gpm	- gallons per minute
hr	- hour
In	- Inch
IPH	- Industrial Process Heat
IR	- Infrared
kW	- kilowatt
L	- Liter
LANL	- Los Alamos National Laboratory
LCC	- Life-Cycle Cost
LMTD	- log-mean-temperature-difference
mg	- milligram
MAX	- maximum
mil	- millimeter
MIN	- minimum
Min	- minute
NPSH	- Net positive suction head
NTU	- Number of Transfer Units
O&M	- Operating and Maintenance
psi	- pounds per square inch
psia	- pounds per square inch, absolute
psig	- pounds per square inch, gauge
PVC	- Polyvinyl chloride
R	- resistance of insulation to heat transfer
Ref.	- reference
RI	- Ryznar Index
rpm	- revolutions per minute

SIR	- Savings-to-Investment
SC	- space cooling
SH	- space heating
SHWR	- solar hot water return
SHWS	- solar hot water supply
sq	- square
SLR	- Solar Load Ratio
SWP	- swimming pool heating
SWPS	- swimming pool-summer only
SWPA	- swimming pool-all season
TSH	- total system head
U	- Overall heat transfer coefficient
UV	- ultraviolet
VAC	- volts, alternating current
VDC	- volts, direct current

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## CHAPTER 1

### INTRODUCTION

#### Purpose

This technical manual provides project managers, project engineers, designers and Operating and Maintenance (O & M) workforce with a clear and concise means of designing, installing, and maintaining active solar energy systems for a variety of applications. These include domestic hot water (DHW), industrial process heat (IPH), space heating (SH), space cooling (SC) and swimming pool heating (SWP).

Systems covered in this manual include active, liquid systems only; systems using air as the heat transfer fluid (collectors) are not discussed. Air systems have a significantly higher parasitic power consumption compared to liquid systems (fans vs pumps) and, when coupled with the slightly lower efficiency of air systems, result in less cost-effective systems. Therefore, air systems are not included in this manual.

The manual is written such that the project manager can follow the design process, from feasibility through installation, step-by-step, with the designer and installer. At each point, the designer can determine what is expected of their design, and the project manager can determine exactly what information to ask for

and expect to receive. Project engineers should be able to determine key design points to be studied, isolate problems early in the design, review and approve submittals knowledgeably, and perform inspections with significant results. Actual system designers will find specific design concepts to be followed based upon proven system designs that eliminate "one-of-a-kind" systems.

O & M workforce personnel using this manual will be able to determine the basis of design used, as well as be able to set up useful O & M procedures to minimize downtime and maintenance costs.

### Philosophy/Background

This technical manual has been written to provide the designers of active solar energy systems with specific system types and design concepts to be followed. That is, standard or "generic" solar energy system designs are presented with tight limitations or allowable variations.

The standard systems and design concepts provided in this manual are based upon the onsite inspection, evaluation, and troubleshooting of more than 100 existing solar energy systems installed at military bases throughout the U.S. These cumulative results have been used to determine which system types, equipment types, and installation details provide the best designs. Although more

complex designs may, in theory, produce a slightly higher energy output, the resulting downtime and increased maintenance costs far outweigh the slight benefit in higher energy output. Essentially, the simpler systems yield an overall larger return in energy produced over the long run because of reduced downtime.

A second key point in preparing this manual is strict adherence to the principle of simplicity in design. This has the advantage of lowering initial cost and more significantly of minimizing maintenance and downtime. A prime example of this is the performance of existing solar cooling systems in the military. Evaluation of these systems indicates that the complexity of these systems and the poor performance shown to date result in higher operating costs (negative savings) and, therefore, payback cannot be achieved.

The manual is divided into sections that follow each phase of the project from initial feasibility study through operational maintenance. It is designed to be used concurrently by both project management and project designers. Management should use the feasibility chapter at the inception of a project to determine if a solar energy system is economically feasible. Assuming a decision is made that a solar system is practicable, the next phase of the project and the next section of the manual require the selection of a specific system type to fit the project. At



this point, both manager and designer should be using the manual and arriving at the same conclusions regarding system type.

Once system selection has been made (and agreed to by management and designer), the project can proceed to the schematic design phase. At this point, the designer should use the manual to determine collector type, array size, flowrate, storage size (or volume), and the system interface. Management should use the manual as a checklist for the design to determine what to expect or demand at the end of schematic design. Completion of schematic design by the designer and approval by management lead into the design development phase where the design is fleshed out to show major details. The designer and management should use the manual in exactly the same fashion as in schematic design: as a design guide and checklist, respectively. Project managers should be aware of and use the "not allowed" lists presented at the end of the sections in Chapter V. Items in these lists have been shown in the field to be inefficient, unreliable, and/or nonfunctional. Avoiding these items in the design is essential to ensure optimum performance and reliability.

Final project design is covered in the next section of the manual entitled "Construction Documents." This section follows the project through 100 percent design with the project ready for construction. This section of the manual covers important installation details and what management should be looking for in

a final critique of the design. Calculation methods for determining thermal loads and collector array sizing are provided in Appendices A and B of this manual, respectively.

Using Chapters VIII, IX and X, the project engineer and O & M workforce can improve inspection techniques, acceptance practice, and development of a good maintenance program. Although the solar energy systems designed using this manual will be inherently easier to maintain than existing systems in the field, turning over the project to the O & M workforce must include certain items if the system is to operate reliably with minimal maintenance. In field evaluations of active solar energy systems in the military, poor planning during this turnover was as much a contributor to creating inoperative systems or high maintenance as poor design.

### **Convention**

The on-site inspections and evaluations of existing systems mentioned previously required the review of many sets of construction drawings. Much confusion existed because of the lack of convention in labeling the solar collector array supply/return lines. For the purposes of this manual, the following convention shall be used:

Return - heat transfer fluid going to the collectors.

Supply - heat transfer fluid coming from the collectors

This convention is in keeping with normal practice in which the collector array is treated like any other heating device such as a hot water generator; the fluid to be heated is labeled "return" and the heated fluid is "supply." This convention shall be used in all design documents.

### Code Requirements

In addition to the design requirements set forth in this manual, all systems designed shall conform to the regulations of the most current edition of the following codes:

1. Uniform Building Code (Ref. 1)
2. Uniform Plumbing Code (Ref. 2)
3. Uniform Mechanical Code (Ref. 3)
4. Uniform Solar Energy Code (Ref. 4)
5. National Electrical Code (Ref. 5)
6. Life Safety Code (Ref. 6)

If a conflict exists between this manual and a code requirement, the code shall be adhered to. The designer shall also adhere to the requirements of all local, state, and/or Federal authorities having jurisdiction.

## CHAPTER II

### FEASIBILITY

#### General

A feasibility study must be performed at the outset of the project to determine if an active solar energy system is economically justifiable for the project. This study must be done before any design effort begins and, therefore, is the responsibility of the project manager.

The active solar feasibility assessment must be performed for the project during the project development stage. It combines Congressional life-cycle costing criteria with state-of-the-art active solar system performance to indicate the relative potential of using active solar applications in the project, according to fuel type and cost.

#### FEASIBILITY ASSESSMENT

The feasibility assessment requires the calculation of the savings-to-investment ratio (SIR) according to the following equation:

$$SIR = (0.50)(A/E_f)(C_f)(UPW^*) - (0.01)(S)(BCF) / 0.90(S)$$

##### a. Assumptions

- (1) 50% solar fraction
- (2) 1% of total investment for O & M expenses

(3) 10% investment tax credit

(4) Energy saved equivalent factor of 1

b. Nonmenclature

(1) SIR = Savings-to-investment ratio

(2) A = Available annual insolation/SF of collector (MBTU/SF)

(3)  $E_f$  = Heating plant system efficiency

(4)  $C_f$  = Cost per unit of fuel saved (\$/MBTU)

(5)  $UPW^*$  = Uniform present worth factor for fuel type

(6) S = System unit cost per SF of collector (\$/SF)

(7) BCF = Benefit cost factor for O & M

If the value for SIR is one or greater for the particular fuel type used, then active solar systems applications for the project are feasible and should be investigated during the design process. If the value for SIR is less than one, active solar applications are not cost effective for the project and should not be considered.

An example using the calculation is as follows:

Project: Install as active solar domestic hot water heating system on a base gymnasium at Tyndall AFB, FL.

Location: Panama City, FL

Feasibility Study: assuming natural gas as fuel type

(1) A = 0.63 MBTU/SF for Panama City, FL

(2)  $E_f$  = 0.75, assuming nat. gas system efficiency of 75%

(3)  $C_f$  = \$4.22/MBTU for nat. gas at Tyndall AFB

(4)  $UPW^*$  = 22.66 for nat. gas, discount factor = 7%, period of 25 yrs, Region 4.

(5)  $S = \$50/\text{SF}$  for system unit cost in 1986

(6)  $\text{BCF} = 11.65$ , assuming 0% differential inflation rate for O & M, which means  $\text{BCF} = \text{UPW}$ . For a 7% discount factor, 25 yr. period,  $\text{UPW} = 11.65$ .

$$\text{SIR} = (0.50) \frac{A}{E_f} (C_f)(\text{UPW}^*) - 0.01 (S) (\text{BCF}) / 0.90(S)$$

$$\text{SIR} = (0.50) \frac{0.63 \text{ MBTU/SF}}{0.75} \frac{(\$4.22)}{\text{MBTU}} (22.66) - (0.01) \frac{(\$50)}{\text{SF}} (11.65) / 0.90 \frac{(\$50)}{\text{SF}}$$

$$\text{SIR} = (0.50)(0.84)(4.22)(22.66) \frac{\$}{\text{SF}} - (5.8) \frac{\$}{\text{SF}} / 45 \frac{\$}{\text{SF}}$$

$$\text{SIR} = \frac{34.4}{45}$$

$\text{SIR} = 0.8$  which is less than 1.0

Therefore, active solar applications are not cost effective for replacing natural gas fuel usage at Tyndall AFB FL, and should not be considered.



## CHAPTER III

### SYSTEM SELECTION

#### General

System selection is the first critical step toward the design, construction, and operation of a functional solar energy system. The standardized systems presented in this manual represent proven concepts that are both simple and reliable. As stated previously, these "generic" systems normally result in overall higher output per annum because they have fewer operating problems with less downtime.

#### Selection

Selection of the appropriate system type is based on a number of general design parameters that should be known to both management and designer at this point in the project. These parameters include the following:

- o Load application,
- o Local environmental conditions,
- o Local water conditions, and
- o Basic structure type (for mounting).

Fig. 1 is a simple logic flow chart to assist the user in making the initial system type selection; these system types represent basic design configurations. Details of design and load interface are covered in subsequent chapters of this manual.





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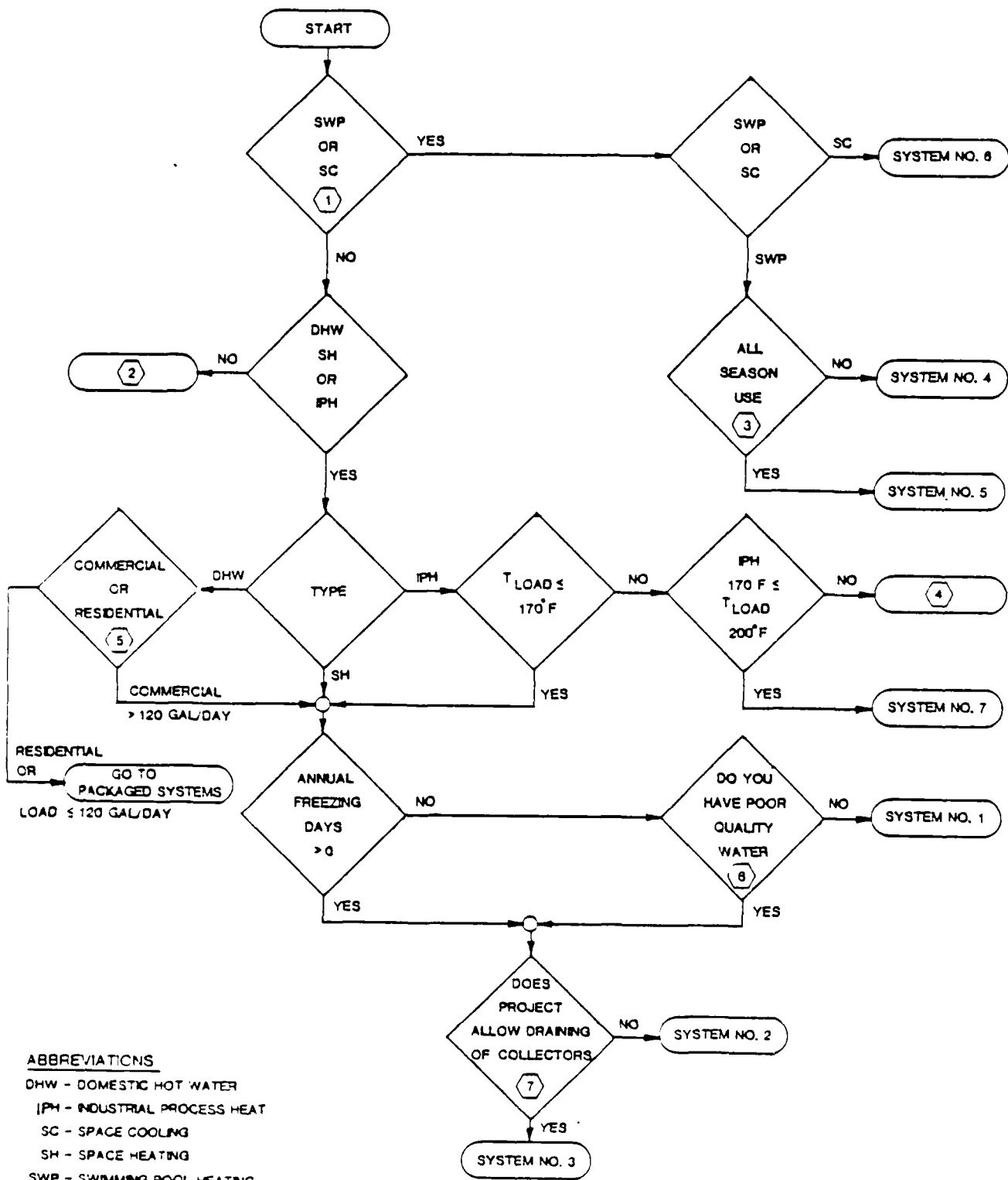


FIG. 1 - SYSTEM TYPE SELECTION LOGIC

## KEYED NOTES:

- 1 A system that combines space cooling with SH, or DHW, or both will normally be dominated by the cooling load imposed and should be considered as a SC system for system selection.
- 2 If the solar system in question is not applicable to one of the five load types in the flowchart, do not use this manual for design.
- 3 All enclosed pools to be used throughout the entire year are considered to be "All Season Use." Outdoor pools in mild climates for which a solar energy system is desired to greatly extend the swimming season beyond the warm weather months should also be considered "All Season Use."
- 4 Industrial process heat systems with required temperatures exceeding of 220°F should be designed with a concentrating type solar collector such as a line-focusing unit. While not overly complicated, concentrating systems are not addressed in this manual. A manual for concentrating collector systems will be produced at a future date.
- 5 Solar systems to be designed for residential use of more than two families per solar system (multi-family housing) should be considered as "commercial" systems. Small commercial buildings with DHW demands of less than 120 gal. per day per Appendix A shall be addressed with packaged DHW systems.
- 6 For this choice, "poor quality water" is to be determined based upon the discussion of water quality analysis contained in Appendix C of this manual.
- 7 This question relates directly to the use of a drainback system. If the architectural or site considerations of the project do not allow for a collector array that is self-draining by design, the answer to this question is "NO". For example, a system requiring ground-mounting of collectors normally cannot be easily drained.

=====

Use of the selection flow chart is designed to allow easy determination of the most applicable system type for the project. Simplified schematics for each allowable system type are shown in Fig. 2 through 7, inclusive.

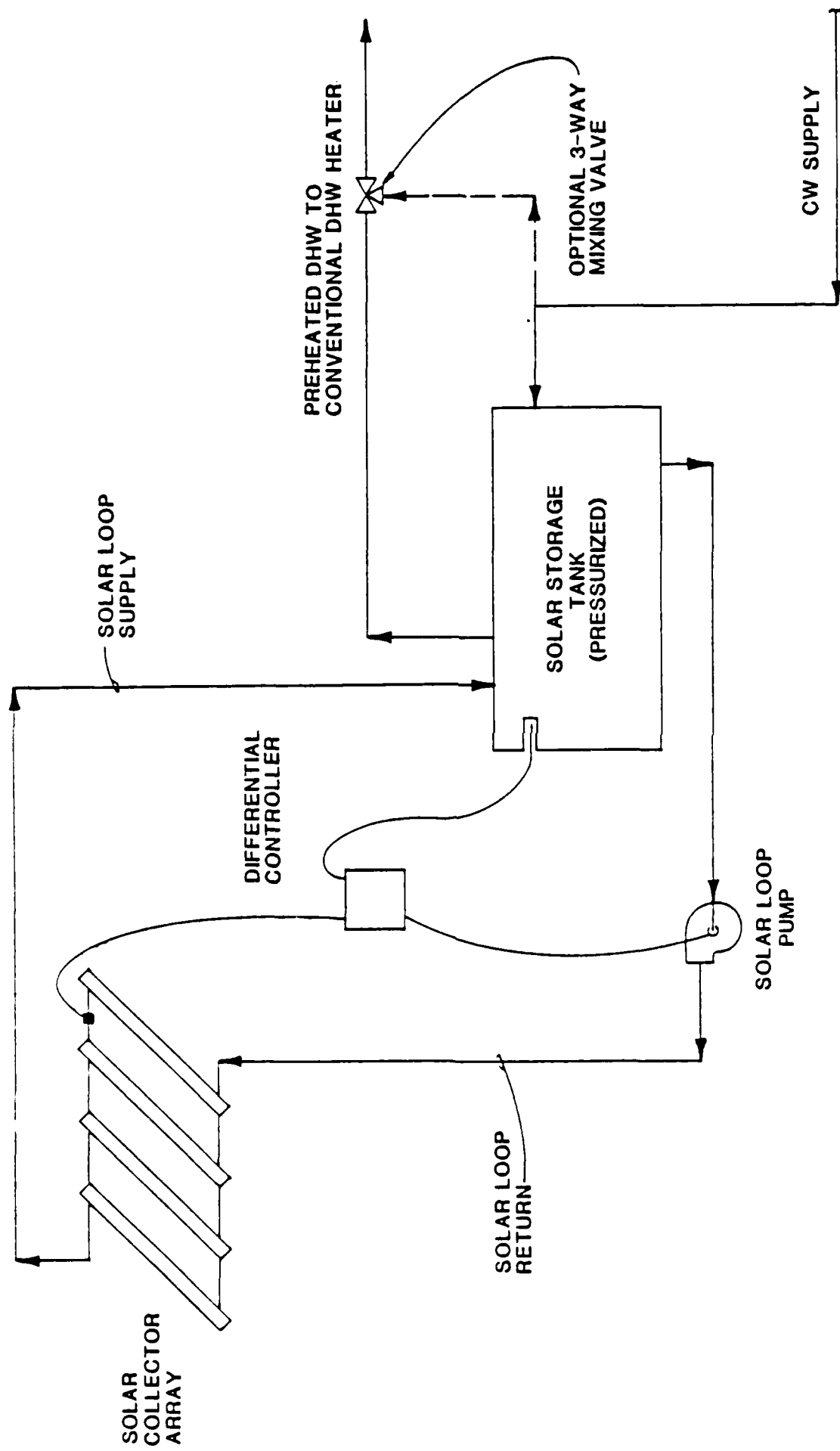


FIG.2 - SYSTEM #1 SIMPLIFIED SCHEMATIC DIRECT RECIRCULATION SYSTEM

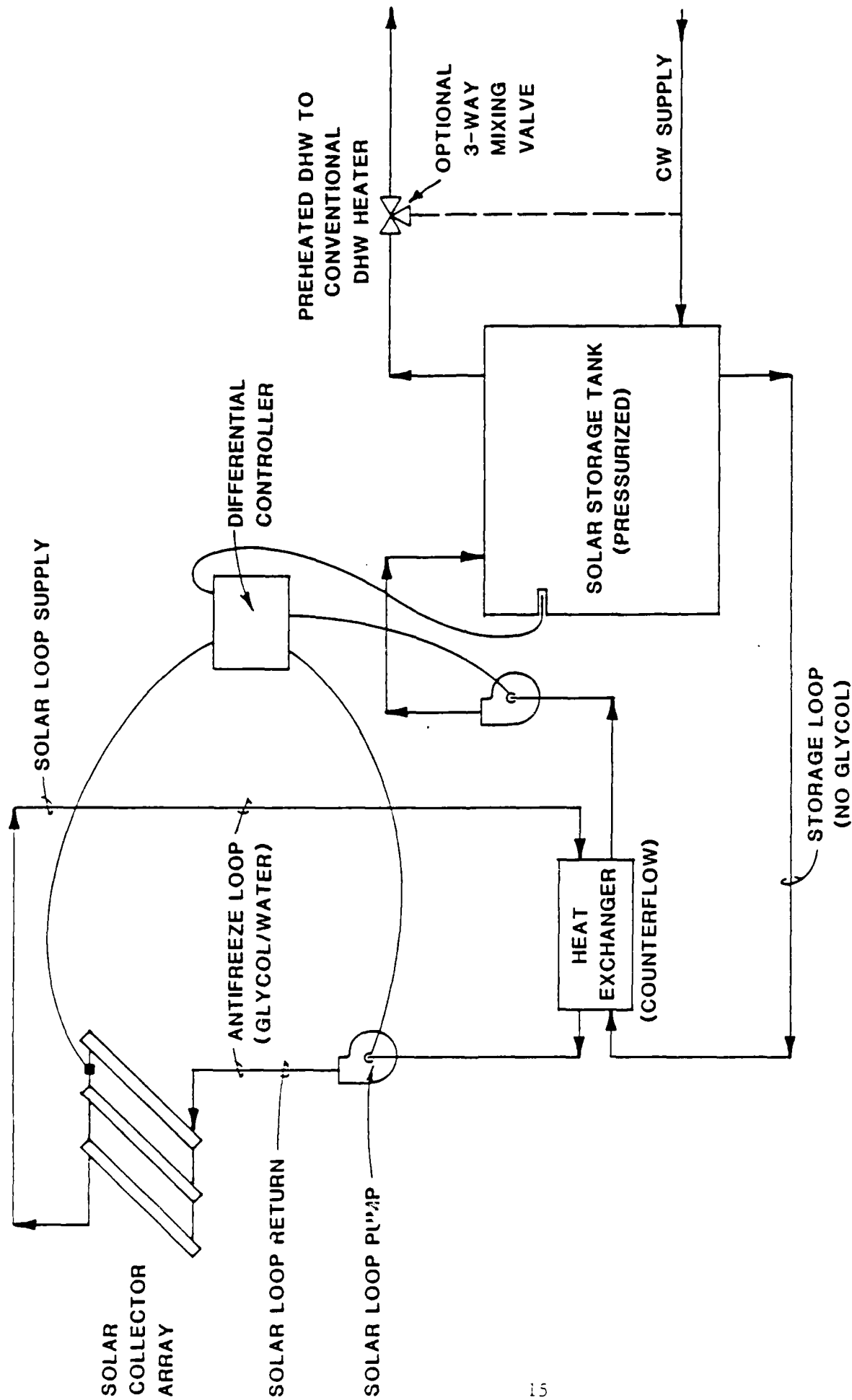


FIG. 3 - SYSTEM #2 SIMPLIFIED SCHEMATIC CLOSED LOOP (ANTIFREEZE) SYSTEM

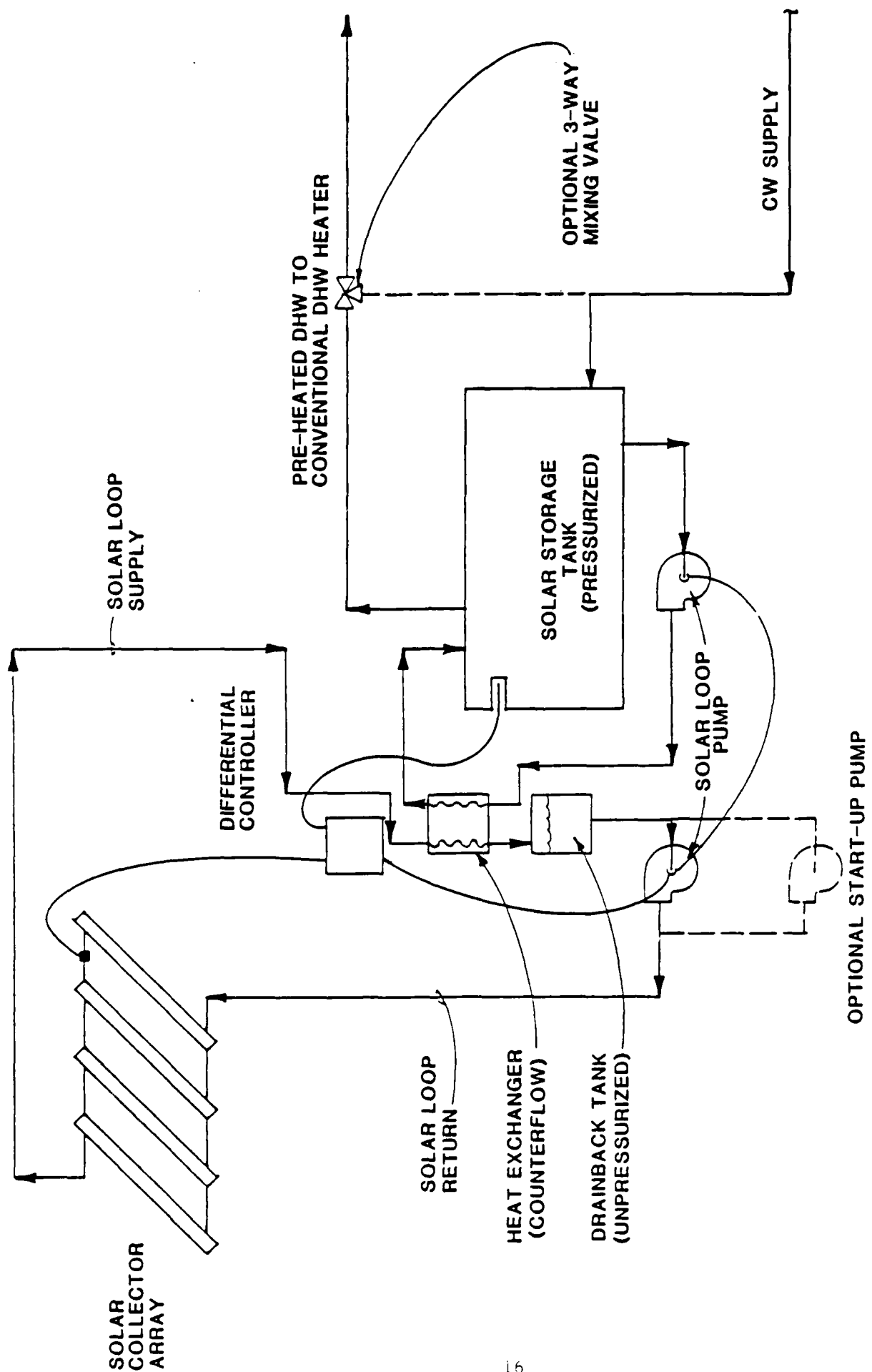
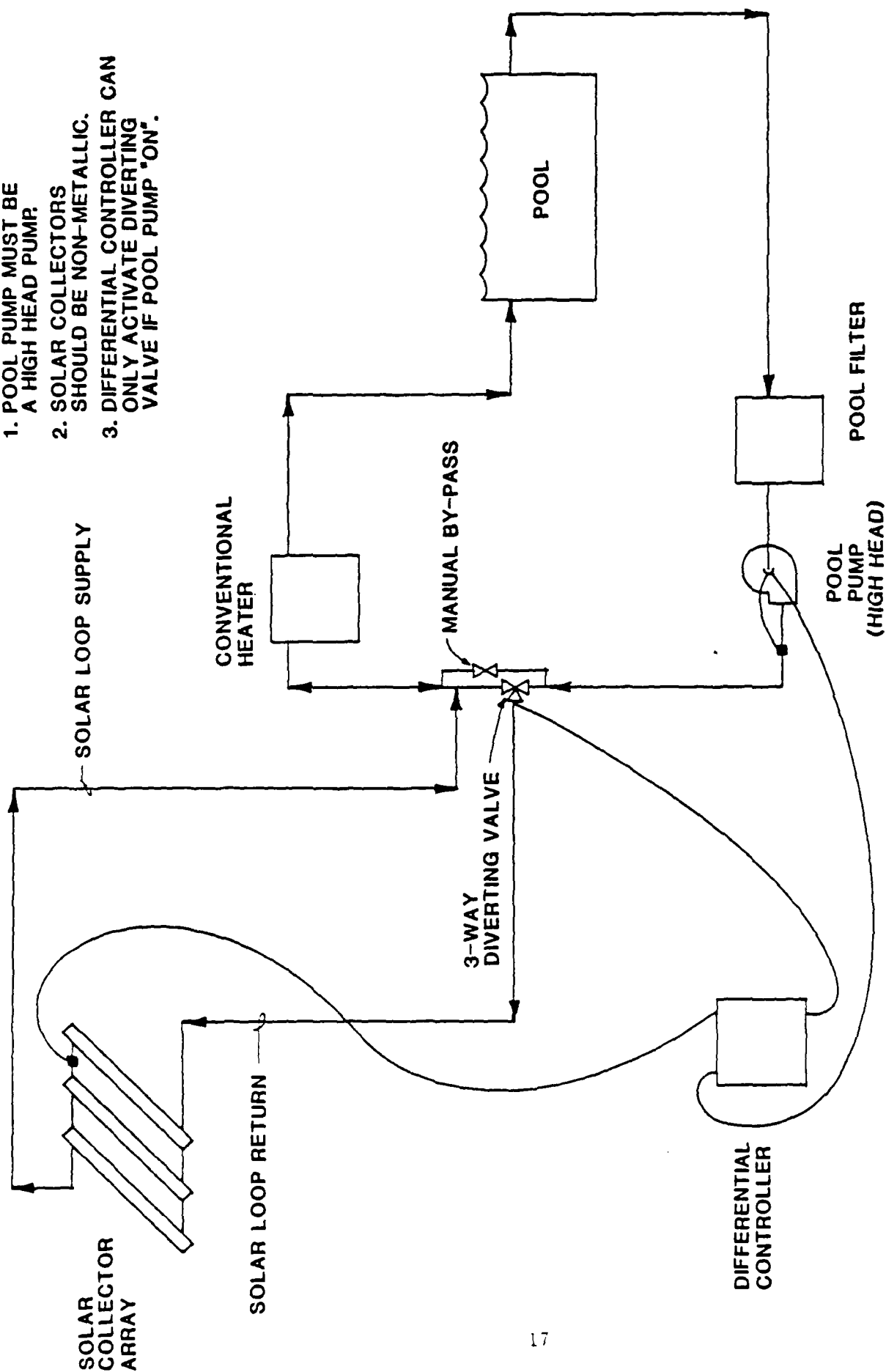


FIG.4 - SYSTEM #3 SIMPLIFIED DRAINBACK SYSTEM

**NOTES:**

1. POOL PUMP MUST BE A HIGH HEAD PUMP.
2. SOLAR COLLECTORS SHOULD BE NON-METALLIC.
3. DIFFERENTIAL CONTROLLER CAN ONLY ACTIVATE DIVERTING VALVE IF POOL PUMP "ON".



**FIG.5 - SYSTEM #4 SIMPLIFIED SCHEMATIC DIRECT POOL SYSTEM**

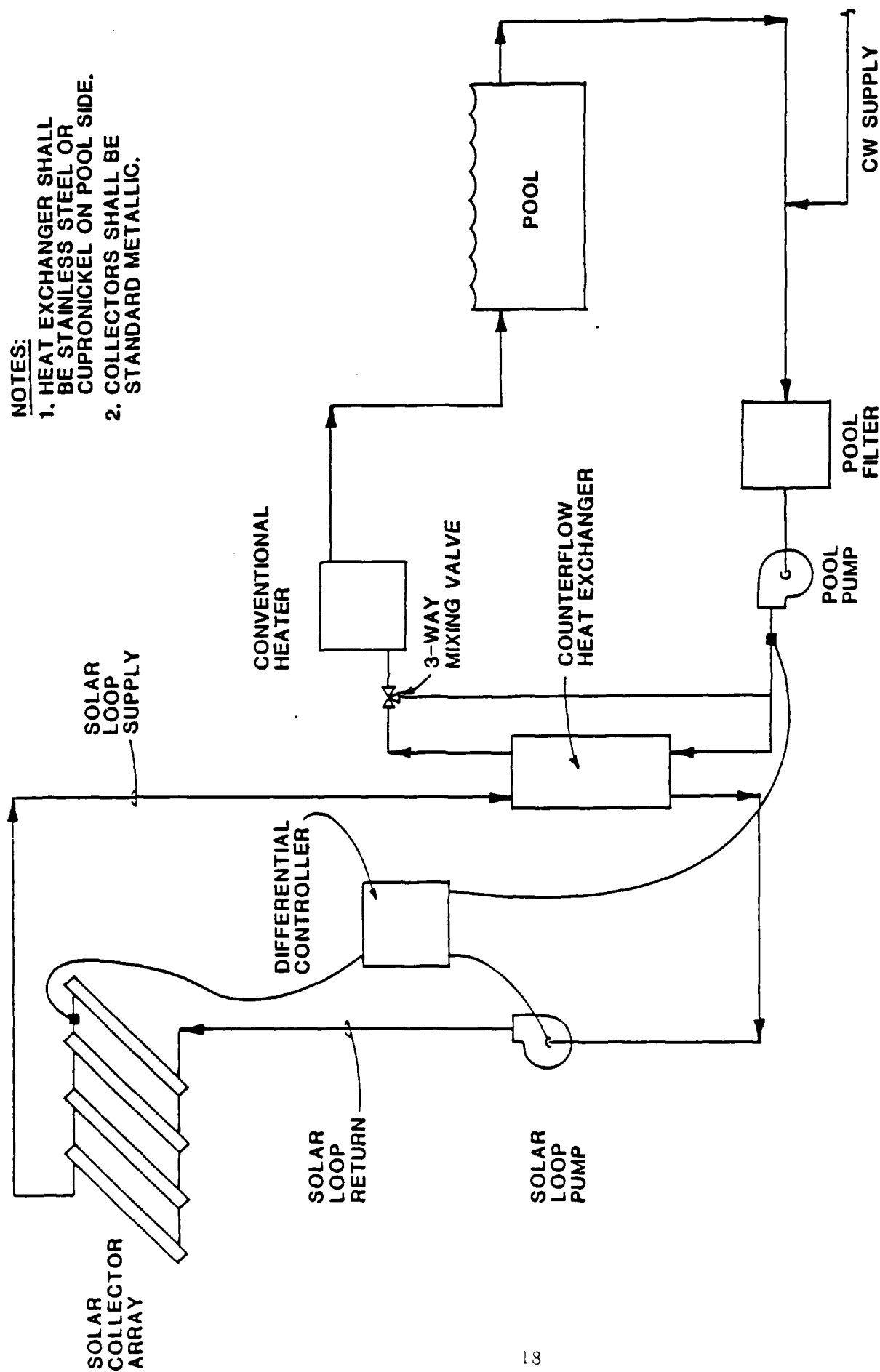


FIG.6 - SYSTEM #5 SIMPLIFIED SCHEMATIC INDIRECT POOL SYSTEM (ALL SEASON)

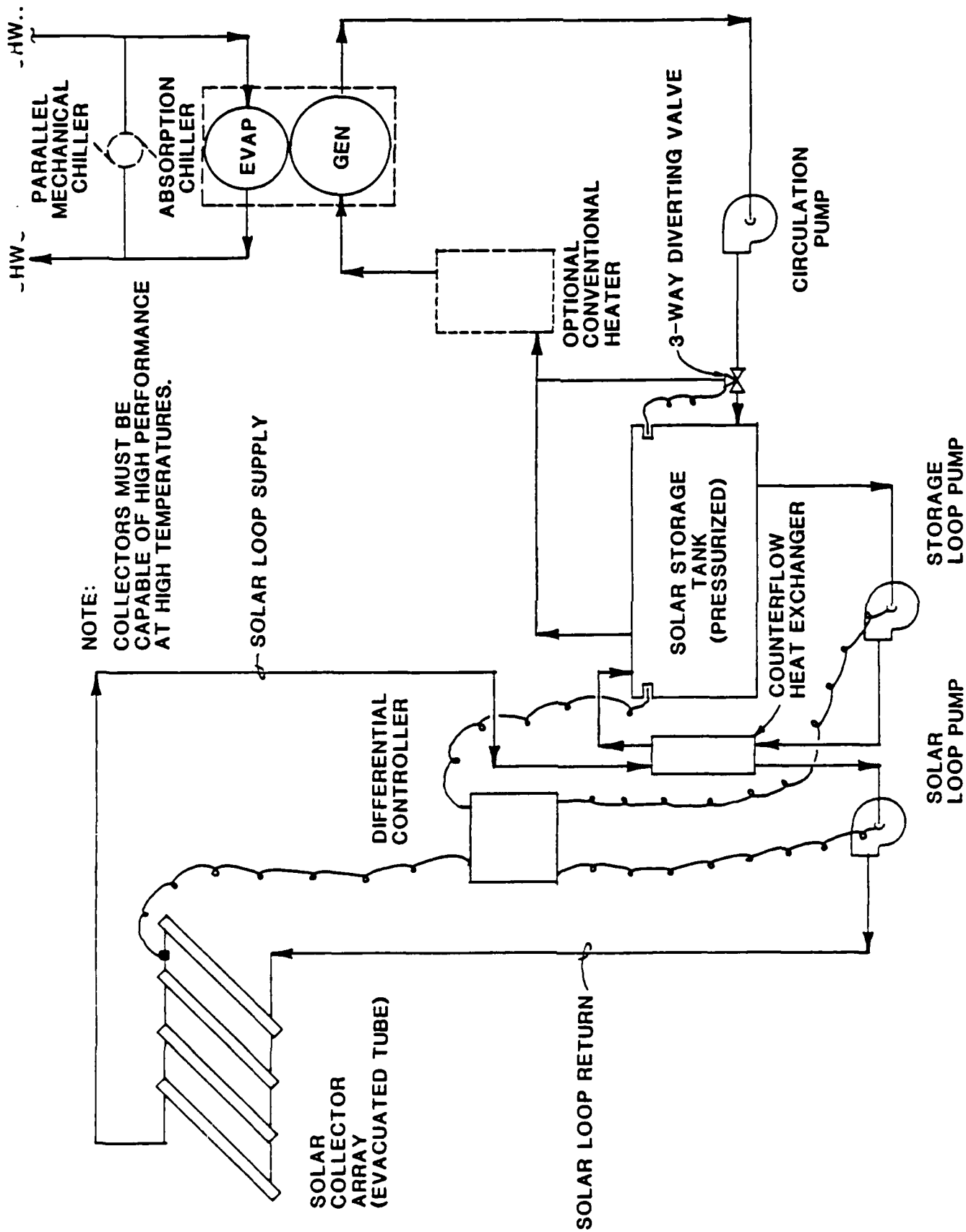


FIG. 7 - SYSTEM #6 SIMPLIFIED SCHEMATIC  
ABSORPTION COOLING SYSTEM (PARALLEL)



System 7, an IPH system operating in the range of 170°F to 220°F, is not shown in schematic form. In this case the schematic layout of the system will be the same as the direct recirculation, or closed-loop anti-freeze, systems except that the collectors must be of the evacuated-tube type.

The designer should be aware that, in many IPH systems, where the thermal loads follow a standard daily pattern, such as 8:00 to 5:00, the system may function more efficiently without any storage (solar). In this situation, the solar system is used whenever solar energy is available in a parallel arrangement with the conventional system.

System 3 is a drainback system with an optional start-up pump in the solar loop/drainback tank interface. Using the start-up pump in the design is dependent upon the vertical distance between the drainback tank and the collector array. If the collector array is more than two stories above the drainback tank, a start-up pump may be required to overcome the initial static head of filling (See Chapter V - Pump Sizing, for further discussion). Once sufficient project information is available to determine the vertical distance between the drainback tank and the collector array, a decision concerning the use of a start-up pump can be made.

Finally, multi-use systems should be selected based on the application with the dominant load. For example, a combination SH and DHW system should be selected for whichever load is greater, SH or DHW. All design parameters would be determined in the same manner.

### Examples of Chart Use

1. A project calls for design of a DHW solar system for a 500 person dormitory project enlisted personnel. The building is in a temperate climate with a positive number of freezing days. Potable water for the site is of high quality. Location of the collector array, relative to the mechanical room, will prevent daily drainback of the collector array. Use of the selection chart would be as follows:

Step #1 - Is the system for swimming pool heating  
or space cooling?

Answer - Neither

Step #2 - Is the system for DHW, SH or IPH?

Answer - Yes - DHW

Step #3 - Is the DHW application commercial or  
residential in size?

Answer - Commercial - see keyed note #5.

Step #4 - Do freezing days occur at the project  
location?

Answer - Yes

Step #5 - Does the project allow for drainback of  
the collector array to the drainback

Answer - No - see keyed note #7.

Step #6 - System type #2 shall be used for this project. This is a closed-loop anti-freeze (glycol) system.

2. Suppose that a project calls for cathodic protection of a remote pipeline and that a photovoltaic cathodic protection system should be investigated. If this manual were used, the following would occur in selecting a system type:

Step #1 - Is the system for swimming pool heating or space cooling?

Answer - Neither

Step #2 - Is the system for domestic hot water, space heating, or industrial process heat?

Answer - No - See keyed note #2. Note #2 states that this design manual cannot be used for designing this type of system and that the user must look elsewhere.

Table 1 lists some of the basic advantages and disadvantages of the "standard" systems. Not all systems are comparable to one another. For example, a nonmetallic swimming pool system (5) cannot be compared to the space-cooling system (7); they are apples and oranges.

### System Descriptions

All of the standard systems have the same basic functions of collecting, storing, and delivering solar energy to a thermal load. The basic operation of all systems is as follows:

1. Solar energy (radiation) is absorbed by the collectors. Energy absorbed by the absorber plate is transferred (conduction) to the heat transfer fluid in the collector risers.
2. When the collector temperature, as sensed in the header by the collector sensor, reaches a temperature X degrees Fahrenheit above the storage tank temperature (or pool temperature), a differential temperature controller will activate the solar loop pump(s). The differential setting, X, is higher for systems with heat exchangers than direct systems:
  - a. Direct systems (no heat exchanger between storage and collectors).  
Differential temperature "on" = 7°-10°F  
Differential temperature "off" = 2°-5°F
  - b. Indirect systems (heat exchanger between storage and collectors).  
Differential temperature "on" = 15°-20°F  
Differential temperature "off" = 5°-10°F

TABLE 1

## SYSTEM TYPE ADVANTAGES/DISADVANTAGES

SYSTEM AND DESCRIPTION NO. TYPE	ADVANTAGES	DISADVANTAGES
1. Direct Recirculation	<ol style="list-style-type: none"> <li>1. Low first cost because simplicity.</li> <li>2. Heat exchangers not required.</li> <li>3. Controls are minimal.</li> <li>4. Attention-to-detail in construction not as critical as drainback systems.</li> <li>5. Fluid maintenance not required.</li> </ol>	<ol style="list-style-type: none"> <li>1. Requires pressure vessel for storage.</li> <li>2. No freeze protection unless heated fluid is circulated at low temperatures (loss).</li> <li>3. Applicable only to areas with good water because of scaling problem. Water in collectors is "once through."</li> </ol>
2. Antifreeze (glycol)	<ol style="list-style-type: none"> <li>1. Can be used in severe freezing climates.</li> <li>2. Attention to detail not as critical as with drainback.</li> </ol>	<ol style="list-style-type: none"> <li>1. High first cost.</li> <li>2. Requires pressure vessel, heat exchangers (double separation), and extensive controls.</li> <li>3. Fluid must be maintained at design level (glycol percent) and inhibitors replaced.</li> </ol>
3. Drainback	<ol style="list-style-type: none"> <li>1. Lower first cost.</li> <li>2. "Passive" freeze protection.</li> <li>3. Fluid maintenance not required.</li> <li>4. Minimal controls.</li> </ol>	<ol style="list-style-type: none"> <li>1. Attention to detail in construction is critical to ensure that drainback occurs.</li> <li>2. Higher head capacity pump or a separate start-up pump may be required.</li> </ol>
4. Nonmetallic swimming pool system	<ol style="list-style-type: none"> <li>1. Lower first cost.</li> <li>2. Minimal maintenance.</li> <li>3. Minimal controls.</li> </ol>	<ol style="list-style-type: none"> <li>1. Not applicable to all season use unless in extremely mild climates.</li> <li>2. Efficiency low.</li> </ol>

SYSTEM AND DESCRIPTION NO. TYPE	ADVANTAGES	DISADVANTAGES
5. Metallic swimming pool system (all season)	<ol style="list-style-type: none"> <li>1. Applicable to all season use in severe climates</li> <li>2. Higher overall efficiency than system 5.</li> </ol>	<ol style="list-style-type: none"> <li>1. Higher first cost.</li> <li>2. Requires heat exchanger (noncopper)</li> <li>3. Fluid maintenance may be required.</li> <li>4. Controls more extensive than system 4.</li> </ol>
6. Space Cooling	<ol style="list-style-type: none"> <li>1. Possible energy savings in areas with high cooling loads and high cost conventional fuels.</li> </ol>	<ol style="list-style-type: none"> <li>1. High first cost.</li> <li>2. Low efficiency.</li> <li>3. Complex controls.</li> </ol>
7. IPH between 170 & 220°F (evacuated tube)	<ol style="list-style-type: none"> <li>1. Higher efficiency.</li> <li>2. Applicable to process loads beyond performance of standard flat-plate.</li> </ol>	<ol style="list-style-type: none"> <li>1. High first cost (relative).</li> </ol>

3. The solar loop pump, while activated, transfers energy from the solar collector array to storage. Systems with heat exchangers employ two pumps, one on each side of the heat exchanger, to accomplish this. Both pumps are controlled as one unit.
4. Once solar energy is collected and stored, it is transferred to the thermal load according to the specific load interface used.

Specific operation of each of the systems shown is as follows:

1. Direct Recirculation- This system operates by using the potable DHW as the collector heat transfer fluid. The entering cold water supply to the building is plumbed directly to the solar storage tank. It is a "once-through" system because the water that passes through the collectors is actually delivered to the thermal load (faucets, showers, etc.). Because no heat exchangers are involved, it is treated as a direct system for differential on/off settings. Freeze protection is accomplished by circulating hot water from the storage tank through the collectors any time the collector temperature approaches freezing. This type of system is used only in mild climates with infrequent freezing and good quality water.

2. Closed-loop (Antifreeze)-This system operates using a separate solar loop and heat exchanger. The solar loop is filled with a mixture of water and glycol (normally 50% propylene glycol). Energy collected by the glycol mixture in the solar collectors is transferred to the storage fluid (water) through the heat exchanger. The glycol mixture is the freeze protection in this system and must be maintained. This system is treated as an indirect system for differential temperature settings.
3. Drainback- The drainback system operates using a separate solar loop and heat exchanger as in system #2 (antifreeze). The solar loop in the drainback system, however, does not utilize glycol for freeze protection. This protection is accomplished by draining the collector loop back to the drainback reservoir (unpressurized) any time the solar loop pumps are off (gravity flow). In this situation, freeze protection is passive, and no controls or valves are involved. However, to accomplish the draining of the entire array, all of the piping, including the collectors, must slope (minimum of 1/8 in/ft) back to the drainback tank. Do not put any check valves in the solar loop to allow for the gravity draining to occur. Therefore, good attention to detail is critical during construction.



The drainback system uses an unpressurized, vented drainback tank and an open collector loop. As such, a static head must be overcome at start-up by the pump but is eliminated once flow is established throughout the loop. This situation is not critical for one-to two-story structures but must be addressed for systems with collectors mounted three or more stories above the tank. This situation is discussed in more detail in Chapter V - Design Development in the pump-sizing section.

4. Direct Pool - The direct pool system operates using the actual pool water as the collector heat transfer fluid. Water is diverted by a control valve downstream of the pool filter and before the conventional heater. Pool water is heated in the collector array and returned to the pool. If the solar collectors cannot provide the necessary heating of the pool water, the conventional pool heater is used. If no solar energy is available, the control valve does not divert pool water to the collectors, and the pool water flows directly to the conventional heater. This type of system is used for "swimming season only" systems, and separate freeze protection is not required.
5. Indirect Pool - The indirect pool system is used for all season pools in climates where freezing occurs. A separate collector loop with a water/glycol mixture

transfers energy to the pool water by a heat exchanger; the glycol mixture provides freeze protection. The heat exchanger used is in direct contact with the pool water and must, therefore, be constructed of stainless steel or cupronickel to avoid corrosion of copper by chlorine. The solar loop is activated when the required differential temperature between collector and pool is reached. The system is inactive when the pool is at or above a user-determined setpoint (desired pool temperature). This setting should be slightly higher than the conventional heater setpoint.

6. Absorption Cooling - This system functions basically the same as the closed-loop antifreeze system as far as the collector loop is concerned. The major differences are that the collector loop operates at a much higher design temperature and that thermal energy collected is delivered to an absorption chiller for cooling.
7. IPH - The IPH system does not constitute a separate system design. The IPH system could be configured as a direct recirculation, antifreeze, or drainback design. The same control logic would apply as described for each of these systems. The primary difference occurs in the load interface where an IPH design normally has a well defined, consistent load. Often, when the process load operates on a specific daily schedule, the IPH system can be used without a storage tank because there is no

need to store energy for later use. In this scenario, the solar array is used much the same as any conventional in-line heater.

It should be noted that systems using silicone-based heat transfer fluids are not allowed within the scope of this manual. This is because this type of system is in limited use at this time and, therefore, its use would not reflect the goal of "standardized" design.

## CHAPTER IV

### SCHEMATIC DESIGN

#### General

Once the project is determined to be economically feasible and a system type has been selected, the project can progress to the Schematic Design phase.

The Schematic Design phase consists of establishing the basic design of the system, including the following:

- o Thermal loads,
- o System type,
- o Collector type,
- o Close approximation of collector array size (including calculation of average yearly solar contribution),
- o Estimated storage size (volume),
- o Solar loop flowrate and collector tilt angle,
- o Load interface, and
- o Basic control logic.

System designers shall prepare the Schematic Design Report discussing each of the required items above for submission to and acceptance by the project manager. This report should discuss calculation of the thermal loads, as shown in Appendix A - LOAD

CALCULATIONS, the selection of the system type as well as the collector type, and any assumptions made in determining the selection.

This report should show calculation of the approximate array size, storage volume, solar loop flowrate, and collector tilt angle as well as a suggested load interface. A single line schematic of the system, including the proposed interface, is required. Pipe size and type, equipment selection, manifolding, and layout detail are not required at this point. The report should, however, outline the basic control logic intended.

### Thermal Load

Calculation of the thermal loads to be addressed by the solar energy system is, obviously, a critical item in the design process. Appendix A of this manual describes the procedures to be used in calculating the thermal loads. These loads are approximate at this point and may change as the overall project develops. The system designer should now proceed to calculate the thermal loads as detailed in Appendix A. Be careful to note any assumptions made in these calculations required by lack of data at this stage of the project. Proceed to the next section after thermal loads have been calculated. If, for DHW systems only, the DHW load for a commercial type project is less than or equal to 120 gal. per day at 120°F, per Appendix A, a packaged DHW system shall be used, and the designer should proceed directly to Chapter XI.

### Collector Selection

Before sizing the overall collector array, the designer should select the type of collector to be used in the array to allow better calculation of collector energy output in sizing the array.

Selection of the collector should be based primarily on the application temperature of the system and the system type previously selected. Within the scope of this manual, three basic collector types are to be considered for all of the system types allowed. These basic collector types are the following:

1. Nonmetallic: This collector is used in "summer only" swimming pool heating systems, is normally fabricated from plastic or other polymer materials, and is unglazed.
2. Standard Flat-Plate: This collector will be used in the majority of projects covered by this manual. For the system types defined in this manual, this collector type will be used for all but system #4, system #6, and the high temperature portion of an IPH system (system #7).
3. Evacuated Tube: This collector type is normally used for high-temperature applications (up to 220°F) in which a fixed (stationary) collector is

required. Temperature applications above 220°F should be addressed using tracking, concentrating collectors, which are not within the current scope of this manual.

Table II indicates the type of collector to be used in conjunction with the various system types defined below:

TABLE II  
COLLECTOR TYPE/SYSTEM TYPE APPLICATIONS

<u>SYSTEM TYPE NO.</u>	<u>COLLECTOR TYPE</u>
1	Standard Flat-Plate
2	Standard Flat-Plate
3	Standard Flat-Plate
4	Nonmetallic
5	Standard Flat-Plate
6	Evacuated Tube
7 170°F to 220°F (IPH)	Evacuated Tube

The systems designer should carefully consider selection of collectors within each type. Poor selection and specification of a collector can cause the failure of an otherwise good design. Considerations for selection of collectors within each collector type are discussed as follows:

## 1. Nonmetallic

The majority of nonmetallic collectors on the market are made specifically for swimming pool heating and, therefore, are quite similar. This type of collector is normally used unglazed and uninsulated because of the low operating temperature (70-100°F) and the high ambient temperature during the swimming season. Therefore, selection of a collector in this category should be based primarily on materials and ease of installation.

Materials should be selected for their durability and resistance to corrosion by various substances. In particular, the material of the collector should be highly resistant to degradation from ultraviolet (UV) radiation. An excellent material choice that meets these requirements is ethylene-propylene-diene-monomer (EPDM) rubber. Ease of installation is the second item to be considered in the selection. This type of collector is inherently inefficient at elevated operating temperatures, and low installation cost (labor) is required to obtain any economic payback.

Collectors of this type normally come in either preassembled absorber modules or as components for site-built arrays. Either of these methods is acceptable with each having advantages and disadvantages. Preassembled modules are usually higher in initial cost, but installation labor is



reduced. Site-built units require more installation labor but have a lower first cost and are more adaptable to a specific site.

## 2. Standard Flat-Plate

This type of collector will be used in the vast majority of projects designed using this manual. It is also the type of collector for which the most products are available and for which the most variations exist. Some of the general categories of standard flat-plate collectors include the following:

- o Single glaze, selective surface;
- o Single glaze, non-selective surface; and
- o Double glaze, non-selective surface.

Within these general categories are also some basic manifolding categories including the following:

- o Internally manifolded and
- o Externally manifolded

For the purposes of this manual and to maintain the basic philosophy of "standard" systems, minimal maintenance and reliability, the following type of standard flat-plate collector should be used:

- o Single glaze, selective surface. The selective surface shall be electroplated or chemically deposited (painted surfaces not acceptable) with

a minimum absorptivity of 0.90 and a maximum emissivity of 0.15.

- o Internally manifolded with four header connections (on sides).
- o Minimum 1.0" header size.
- o Copper fluid passages (risers), copper tube with aluminum fin allowed.
- o Mounting of collector shall not require drilling of collector box assembly.
- o Absorbers and headers shall not be rigidly attached to collector box to allow for expansion.
- o The collector box shall be metal with a corrosion resistant coating.
- o All collector enclosures shall have "weep holes" to allow drainage of condensate.

The reasons for selection of this type of flat-plate collector include the following:

1. A single glaze, selective surface collector maximizes input with minimal losses (reradiation).
2. Single glaze collectors have less weight and thereby result in smaller roof loads with lower initial and replacement costs.
3. Selective surfaces (electroplated or other chemical deposition) have longer life expectancy, minimal maintenance, and higher performance.

4. Internally manifolded collectors reduce piping (material) and labor costs over externally manifolded collectors.
5. Copper risers are best suited for corrosion control.
6. Minimum 1.0" header size allows maximum flexibility in array design and keeps friction losses low.
7. Four connections per unit (headers) allow flexibility and minimize piping requirements.
8. Mounting without drilling maintains integrity of unit and eliminates source of possible internal damage.

After narrowing the possible selections down to those that meet the above criteria, a specific product (or group) can be selected by comparing their respective performance curves (Instantaneous) with special attention given to the point on the curve most applicable to the project. Fig. 8 shows a set of six first-order, instantaneous efficiency curves for this type collector. Manufacturer's names have been intentionally deleted, but all meet the collector criteria previously stated. The equation for the curves shown is given by:

$$EFF_I = T_{In} - T_{AMB}/I$$

where

$EFF_I$  = Collector's instantaneous efficiency

$T_{In}$  = Inlet temperature (fluid) to collector ( $^{\circ}F$ )

$T_{AMB}$  = Ambient temperature ( $^{\circ}F$ )

$I$  = Insolation value ( $Btu/Ft^2-hr$ )

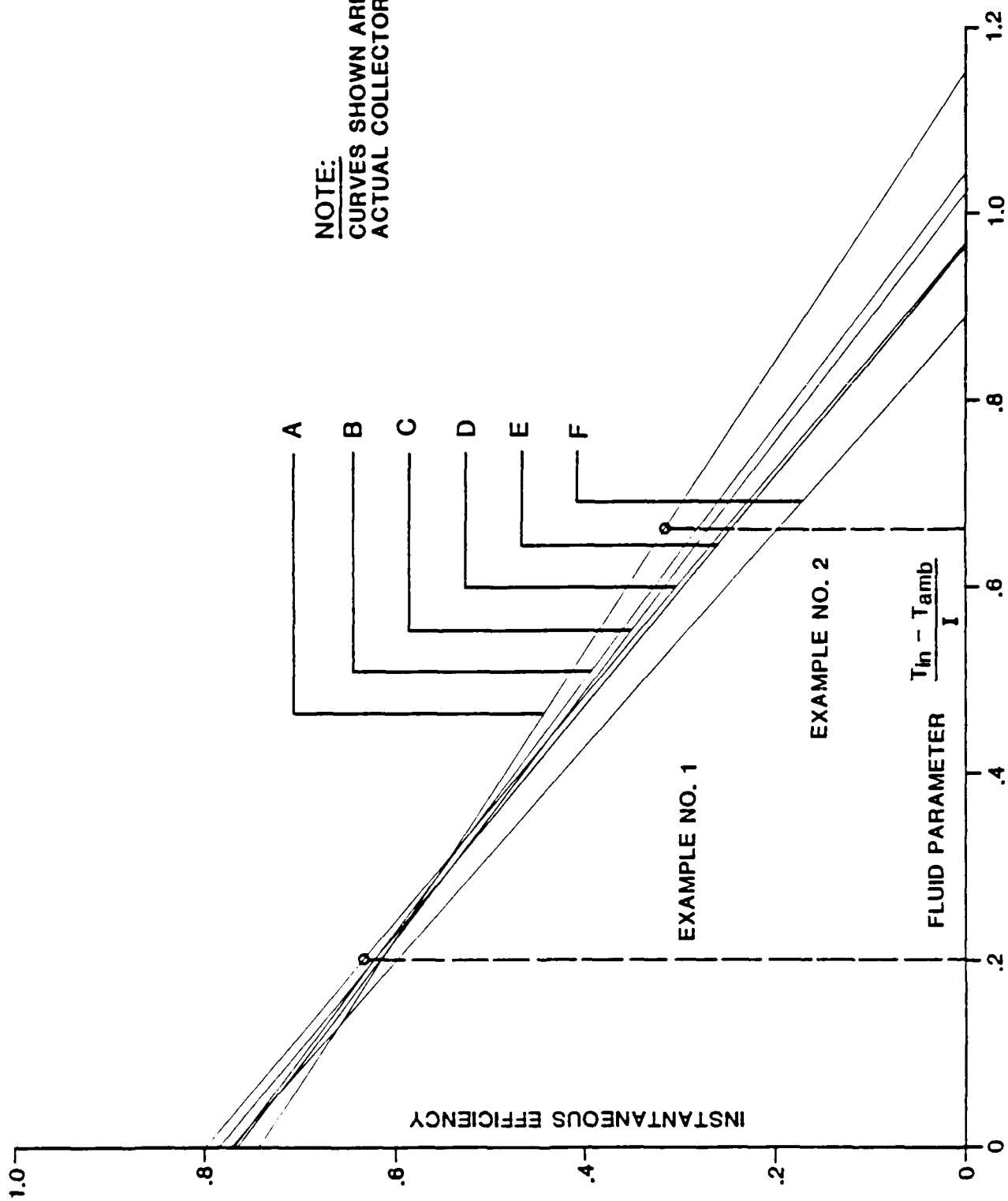


FIG. 8 - COLLECTOR EFFICIENCY CURVES

Using general information about the project and some basic assumptions determines the most logical operating point on the curve for the collector to be selected. Note that these are "Instantaneous" efficiency curves. Table III contains default values for collector input temperature for use by inexperienced personnel.

#### Example 1

Select a collector for use on a DHW system in San Diego, CA.

Supply temperature desired is 120°F.

Assume:

$$T_{In} = 110^{\circ}\text{F} \text{ (10}^{\circ}\text{F less than supply)}$$

$$T_{AMB} = 60^{\circ}\text{F} \text{ (average for year)}$$

$$I = 250 \text{ BTU/ft}^2 \text{ hr (good day -- few clouds)}$$

Therefore, the fluid parameter (Delta T) would be:

$$110 - 60 / 250 = 0.2$$

At this point on the graph, the collector with the highest instantaneous efficiency is "D."

#### Example 2

If a process system (IPH), operating at, say, 150°F, were to be designed for a much more severe climate with low insolation values the selection would differ as shown:

Assume:  $T_{in} = 140^{\circ}\text{F}$   
 $T_{AMB} = 40^{\circ}\text{F}$   
 $I = 150 \text{ BTU/ft}^2 \text{ hr}$

Then

$140-40/150 = 0.67$  and,

returning to the curve yields collector "F" as the most efficient unit for the job.

TABLE III  
COLLECTOR INPUT TEMPERATURE DEFAULT VALUES

APPLICATION	COLLECTOR INPUT TEMPERATURE, °F
-----	
DHW	110
SWIMMING	80
SPACE HEAT	120
SPACE COOL	160
IPH	140*
-----	

\*IPH can be required at virtually any temperature. A value of  $140^{\circ}\text{F}$  is given for example only.

The most efficient collector is not necessarily the best collector to be used on the project. That decision should be based on a rough calculation of cost per unit of energy delivered (\$/BTU) for a number of collectors. The simplest method for deciding this is as follows:

1. For the type of collector required, obtain cost estimates for the array size needed, delivered on-site (F.O.B. project site). Based on the cost estimates provided, calculate the cost per square foot (aperture) of each collector.
2. Graph the instantaneous efficiency curves of the collectors as shown in Fig. 8.
3. Select a high and low operating point for the system and, using the efficiency curve graph, calculate the instantaneous efficiencies of each collector at each point.
4. Multiply the calculated efficiency by the assumed insolation at each design point to obtain energy collected per square foot (aperture).
5. Divide the cost per square foot (aperture) from item one above, by the calculated collected energy from item four to obtain the cost per BTU per square foot (aperture) for each collector.

6. The collector with the lowest cost per BTU is the best choice for the project.

A final point in selecting a collector is the overall size of the unit. The larger the unit, the more collector area obtained per unit installed. That is, a 4.0' x 8.0' collector has 32 square feet of area, whereas a 3.0' x 6.0' unit has only 18 square feet. If each unit has four connections to be made (except for the ends of the row), then the labor involved in installing 32 square feet is approximately equal to that for installing 18 square feet. On a large array, the size results in a significant difference in installation costs. For a 3000 square foot array, approximately 94 4.0' x 8.0' units are required, whereas 167 3.0' x 6.0' units would be needed. These variations in installation cost extend to other items as well and, therefore, the larger units will normally be more economical. First costs, in dollars per square foot of collector, are usually less also.

### 3. Evacuated Tube

Selection of an evacuated tube collector is similar to selection of a standard flat-plate collector. Evacuated tube collectors reduce convective and conductive heat losses by using a vacuum between the glazing and the absorber surface. Because a vacuum would cause a typical flat-plate collector to collapse, this technique is used in conjunction with a tubular design. Vacuums on the order of  $10^{-4}$  torr eliminate



both convection and conduction losses. Evacuated-tube collectors lose less heat to the environment than flat-plate collectors do and they can operate at higher temperatures ( $>200^{\circ}\text{F}$ ). They can collect both direct and diffuse solar radiation, do not require tracking, and because evacuated tubes can operate at lower insolation levels, they can collect more energy on cloudy days. The vacuum also makes the evacuated tube much less susceptible to wind-induced thermal losses than other types of collectors. Another advantage is that with the selective surface of the absorber contained in a vacuum, greater stability and a longer life for the coating can be expected.

The field layout of evacuated-tube collectors is similar to that of flat plates; either roof or ground-mounting is acceptable. Insulated headers are usually supplied with these collectors. Because of the fragile nature of the tubes, care should be taken to protect the array from vandalism.

There are only a few types of evacuated tube collectors on the market. One design employs three concentric glass tubes. Fluid flows into the annular space between the inner and the second tubes and back out the inner tube. The annulus between the second and third (outer) tube is evacuated, and the outside of the second tube contains a selective coating. Another design employs only two concentric glass tubes; the space between them is evacuated,

and the outer surface of the inner tube contains the absorptive coating. A metal fin conforms to the inside surface of the inner tube and attached to this fin is a metal U-tube, which carries the fluid. The U-tube readily accommodates thermal expansion, and glass breakage will not result in a leak. However, cases of copper oxidation caused by stagnation temperatures have been reported and it is recommended that stagnation temperatures be avoided.

The performance of evacuated-tube collectors can be substantially different from that of flat-plates at off-normal incident angles. As the sun angle gets lower, the effective gap between the tubes shrink, thereby increasing the efficiency of panels without specular reflectors. The type of reflectors used has a large effect on off-normal performance, and although it is not evident from a solar noon efficiency curve, the effects of incident angle can give an evacuated tube an advantage in day-long performance, compared with flat plates.

Although flat-plate collectors typically are limited to operating temperatures under  $180^{\circ}\text{F}$ , evacuated-tube collectors can perform at temperatures of  $250^{\circ}\text{F}$ . Evacuated-tube collectors are more fragile, however, and glass breakage has been a problem. In some cases, "shocking" a stagnating collector array with cold fluid has caused the breakage and in other instances, local thermal gradients during stagnation have been the cause.

Therefore, evacuated-tube collectors should not be filled when they are hot and should not be allowed to stagnate when they are filled. The latter consideration dictates the need for extreme care in expansion tank sizing and selection of PRV's. Field experience has shown that borosilicate glass is more durable than soda-lime glass in these applications.

### Collector Array Sizing

At this point in the design, the system type from Chapter III should have been selected and the thermal loads calculated. The system designer can now calculate the approximate overall collector array size using the sizing calculations detailed in Appendix B - COLLECTOR SIZING TECHNIQUES. In calculating the size of the collector array, use the following boundary conditions and/or limitations:

1. Calculations of array size shall be based on a ratio of solar energy supplied to total energy required (solar fraction) of 60-65%, on an average annual basis, as a design goal. This goal cannot always be achieved, but, to maintain the overall design philosophy of generic or standard systems, the acceptable annual solar fraction range shall not be less than 40% nor more than 70% of the total thermal load on an annual average. That is, if the annual thermal load calculated for the project is, for example, 100,000,000 Btus, the solar energy system shall be sized to provide not less than 40,000,000 or more than 70,000,000 on annual average.

The system may provide 95% in a summer month and 25% in a winter month, but the average annual percentage should fall between 40% and 70%.

2. Array sizing and all system parameters based upon array size shall be calculated on the basis of collector net aperture area not gross area. That is, if the calculations for a particular system call for 2,000 square feet of collector then the collectors used on the project should have a net aperture area of 2,000 square feet. Gross collector area varies from one product to another and should not be used for sizing or purchase.

After completing the collector sizing calculations using Appendix B and the boundary conditions set forth above, the designer can proceed to size the storage volume needed as described below.

#### Storage Volume Sizing

Sizing of the storage volume can proceed as soon as the collector array has been sized, as shown above. For the purposes of this manual, the storage medium for all the "standard" systems shall be water. System 2, the antifreeze system, does not use the glycol mixture as a storage fluid; the glycol mixture is contained only in the solar collector loop.

Sizing of the storage volume is relatively simple and is based on a ratio of storage to collector array area. Optimum performance occurs when the ratio of storage volume to collector area is approximately 1.8 gallons ( $H_2O$ ) for each square foot (aperture area) of collector area. This ratio is not an exact number and can be varied somewhat depending on the specific project. For example, a system requiring higher temperature thresholds (i.e., cannot use water at less than  $140^{\circ}F$ ) will perform slightly better if the storage volume is reduced to, say, 1.5 gal/sq.ft., or a system that collects energy all day without a thermal load present may perform better if the ratio is raised to 2.1 or 2.2 gal/sq.ft.. However, with the exceptions listed below, the storage-to-collector ratio should not be less than 1.5 nor more than 2.3 gal/sq.ft. of collector area for use with the standard systems described in this manual.

Exceptions:

1. Swimming pool heating systems do not use a separate solar storage tank but use the pool itself as the storage unit. The ratio of storage to collector does not apply.
2. Certain IPH systems will prove more economically feasible if no solar storage is used. Specifically, an IPH system in which the load occurs only during the regular work day (say 8:00 A.M. to 5:00 P.M.) does not necessarily require a storage tank because the energy collected can be used immediately. In this situation, the collector array operates as an instantaneous heater only and provides heating when it can.

Once a specific ratio has been decided upon, the approximate storage volume can be determined. The storage volume calculated can be adjusted slightly and designers should use standard, off-the-shelf tanks. Do not specify a custom-built tank for the sake of a few gallons ( $\pm 10\%$ ).

### Solar Loop Flowrate

Once the collector array has been sized, the solar loop flowrate can also be calculated. Past experience indicates a range of flowrates, based on collector square footage, that provides an optimum performance for generic solar systems.

As a design criteria, the solar loop flowrate should be calculated to be 0.025 to 0.03 gpm per sq.ft. of collector. The flowrate should never be less than 0.01 or greater than 0.04 gpm/sq.ft. of collector. The lower the flowrate, the greater the differential temperature (rise) across the array; higher flowrates will decrease the temperature rise but increase friction losses and pump requirements. One exception to these requirements is the nonmetallic collector system for swimming pools; manufacturers' recommendations should be followed for these systems because the pool pump is used instead of a separate solar loop pump dedicated to the solar system.

### Collector Array Azimuth and Tilt Angles

The collector array should face as close to true south (not magnetic) as possible. This angle is the collector azimuth angle. The collector azimuth angle may be varied away from true south by as much as  $\pm 15^\circ$  east or west without excessive loss. If project requirements demand that the azimuth angle be more than  $\pm 15^\circ$  off of true south, the feasibility of the solar system should be reconsidered using reduced solar (insolation) availability.

The tilt angle of the collector array (measured from horizontal) is calculated by the application of the solar energy system and the latitude of the project site. Table IV shows the recommended tilt angle of the collector array, relative to latitude, for the types of systems included in this manual. These angles also have a degree of flexibility, and the actual angle used should be adjusted to minimize complexity in construction. For example, if the calculated tilt angle is  $41.5^\circ$ , the designer should specify  $45^\circ$  because of the simplicity of construction at  $45^\circ$  versus  $41.5^\circ$ . Adjustments of  $\pm 5^\circ$  will not seriously affect the performance of the solar system.

TABLE IV

COLLECTOR TILT ANGLES

<u>APPLICATION</u>	<u>TILT ANGLE</u>
DHW	Latitude
DHW + SH	Latitude + 10°
SH	Latitude + 15°
SC	Latitude - 15°
IPH	Latitude
SWPS (Swimming Pool-Summer)	Latitude - 15°
SWPA (Swimming Pool-All Season)	Latitude

Load Interface

At this point in the project, it is often difficult to determine the specific requirements of interfacing the solar energy system with the thermal load of the project. This is especially true with new construction compared with retrofit projects in which existing equipment is known. However, in most situations some basic design parameters can be assumed based on knowledge of the type of system required (DHW, IPH, SH, etc.) to allow an initial interface design.



The basic philosophy to be followed for interfacing the solar and conventional heating systems is as follows:

1. Maximize the use of the solar energy collected.
2. Minimize the complexity of the interface and, thereby, keep control requirements to a minimum.

Fig. 9 and 10 show some simple schematics for interfacing the solar and conventional heating systems for DHW loads. Swimming pool system interfaces (system types 4 and 5) are shown in Fig. 5 and 6 as part of the system type design.

#### Control Logic

Control logic for the solar energy system should be kept as simple as possible. Evaluation of existing systems at military installations indicates that in almost every case, control problems are the major cause of system malfunction or failure. In most instances, the control systems are overly complex or are custom-built (one of a kind) and prove to be maintenance nightmares. The following parameters should be followed in designing the control system:

- o Minimize the control functions;
- o Use off-the-shelf equipment of good quality - do not use custom, one of a kind systems.
- o Do not allow control systems to be designed by the construction contractor. Design of the control system is the job of the designer.

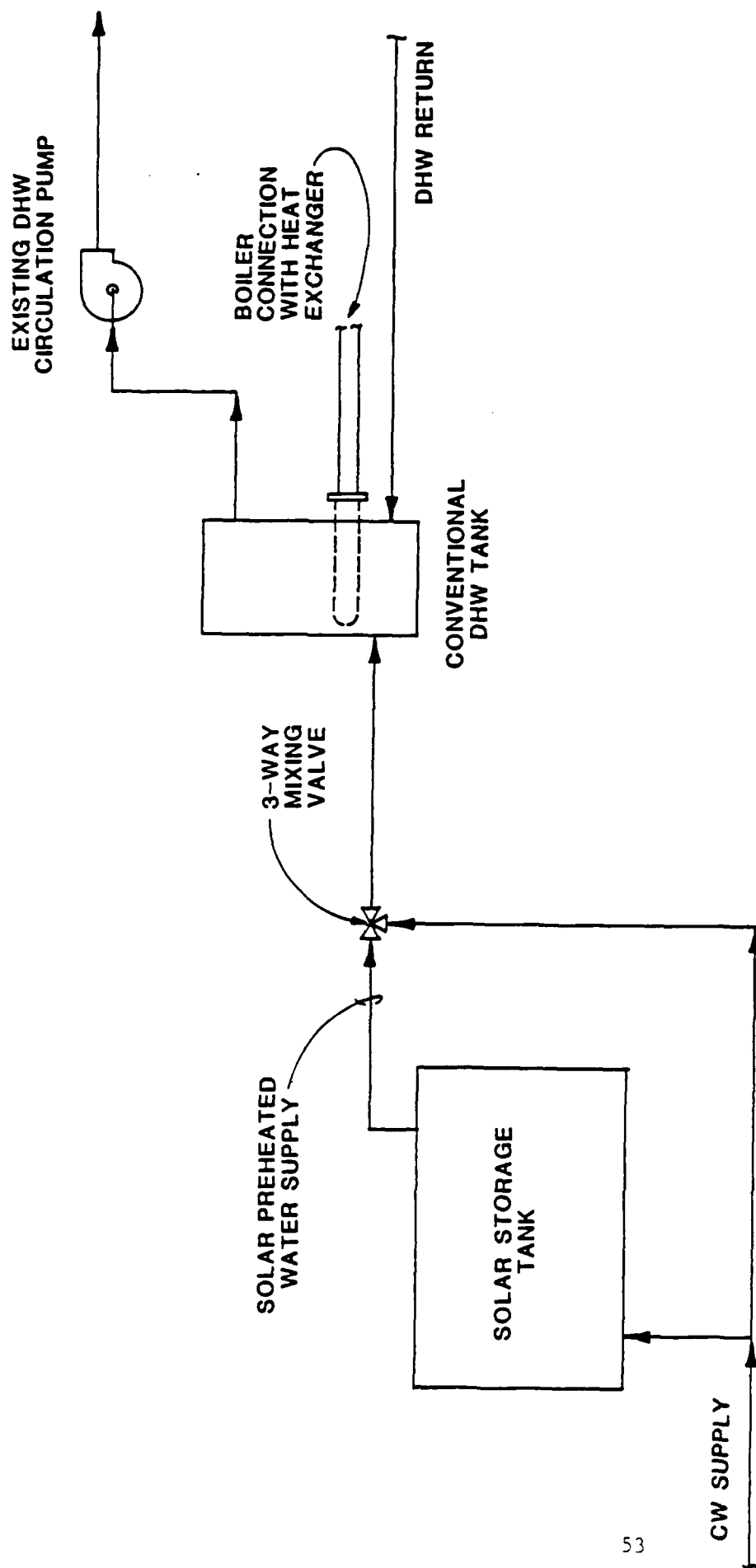


FIG. 9 - OPTION "A" SOLAR/CONVENTIONAL INTERFACE DIRECT PREHEAT WITH MIXING VALVE

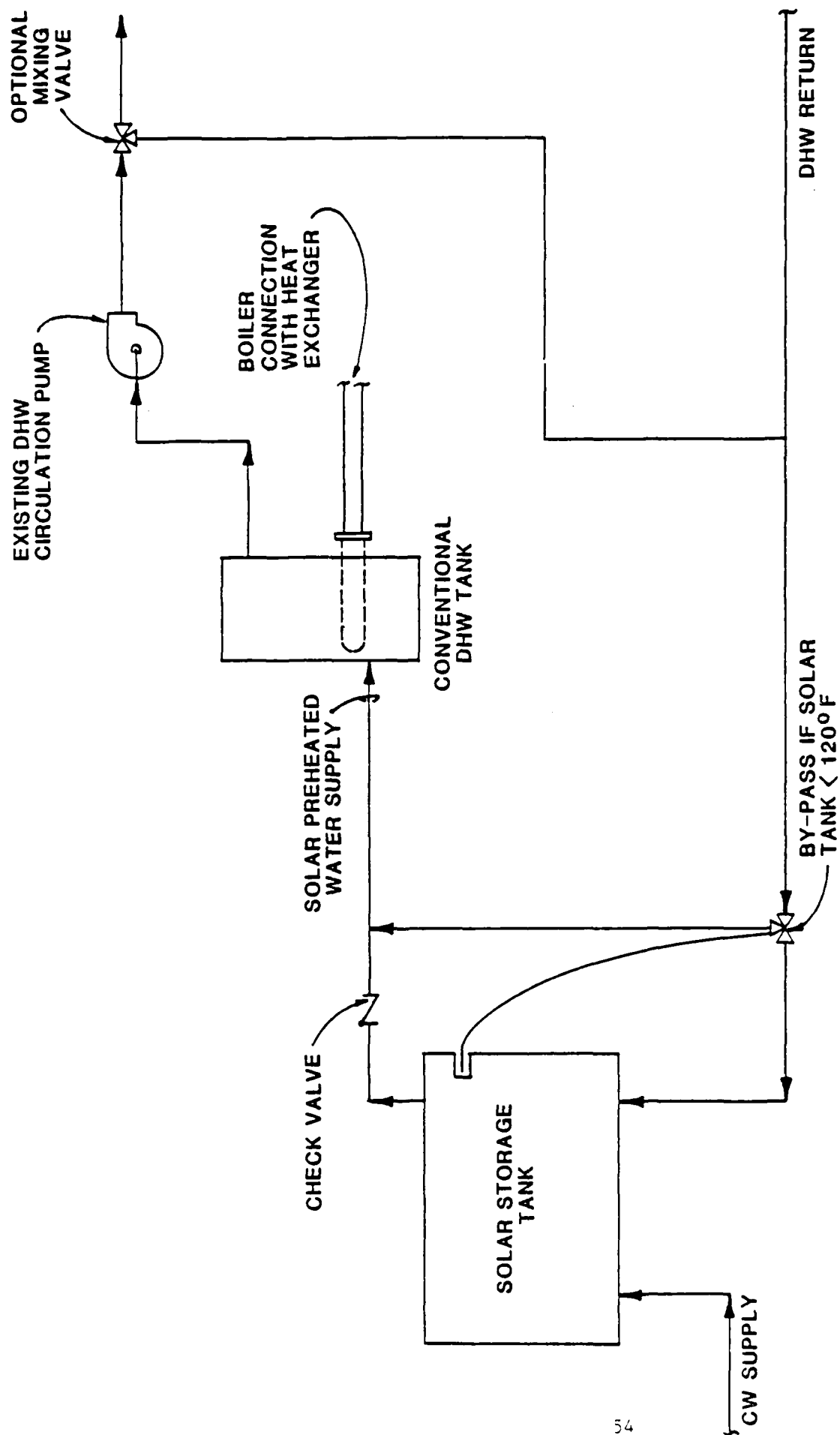


FIG. 10 - OPTION "B" SOLAR/CONVENTIONAL INTERFACE  
DIRECT PREHEAT - INDIRECT RECIRCULATION

At this stage of the design, the control logic needs only show the basic control equipment and equipment to be controlled, as shown previously in Fig. 2 through 7. The basic control logic should also be stated, including on/off differential settings, high limits, and load control valve switching (DHW mixing valves, etc.)

For on/off differential temperatures for a solar loop pump, the following should be used:

- o Collector loop with no heat exchanger between collector array and storage.  
Differential "on" = 7°-10°F  
Differential "off" = 2°-5°F
- o Collector loop with heat exchanger  
Differential "on" = 15°-20°F  
Differential "off" = 5°-10°F

## SCHEMATIC DESIGN CHECKLIST

<u>ITEM</u>	<u>CHECK</u>	
	<u>YES</u>	<u>NO</u>
1. Thermal loads were calculated using Appendix A of this manual?.....	_____	_____
2. System type was selected following the logic chart of Figure 1?.....	_____	_____
3. Collector type was selected and agrees with Table 1?.....	_____	_____
4. Collector array size was calculated using Appendix B of this manual?.....	_____	_____
5. Array size is based on aperture area of collector?.....	_____	_____
6. Solar fraction is in the range of 40 to 70% of the calculated thermal loads?.....	_____	_____
7. Storage volume is in the range of 1.5 to 2.3 gallons per sq. ft. of collector?.....	_____	_____
8. Solar loop flowrate is in the range of 0.01 to 0.04 gpm per sq. ft. of collector? (Except nonmetallic pool collectors).....	_____	_____
9. Azimuth angle is $\pm 15$ degrees of true south?.....	_____	_____
10. Tilt angle is $\pm 15$ degrees of the project site latitude?.....	_____	_____
11. Load interface is as shown in Figures 9 and 10?.....	_____	_____
12. Differential controller is used for solar loop control?.....	_____	_____
13. Storage sensor is shown "in storage"?.....	_____	_____

\_\_\_\_\_ Initials

## CHAPTER V

### DESIGN DEVELOPMENT

#### General

Completion of the Schematic Design and approval by project management allows the designer to move the project into the Design Development phase. Completion of this phase should bring the project to approximately the 70 percent stage.

The Design Development phase of the project consists of finalizing the basic system design (thermal loads, array size, etc.) and fleshing out the design, including the following:

- Finalizing thermal loads,
- Finalizing system parameters (array size),
- Collector layout and manifolding,
- Pipe sizing,
- Thermal expansion control (piping),
- Fluid expansion,
- Drainback tank,
- Storage tank and piping,
- Valving and fittings,
- Pump selection,
- Heat exchanger sizing and selection,
- Insulation,
- Finalizing load interface, and
- Finalizing control system.

System designers shall prepare the Design Development documents noting any changes made from the Schematic Design. Design Development documents shall be submitted to the project manager for approval.

#### Thermal Loads (Final)

The designer shall determine if any changes in the scope of the project affect the thermal loads calculated in the Schematic Design phase. If so, the designer shall recalculate the thermal loads to be addressed by the solar energy system. If changes in the scope of the project result in significant variation of the thermal loads, the designer shall inform the project manager. This is of particular importance if thermal loads increase significantly. In this case, the project manager shall decide whether the previous feasibility study must be redone before design continues. Care must be taken to ensure that thermal loads are calculated consistently throughout the project.

#### Collector Array Sizing (Final)

The designer shall recalculate the collector array size if the finalized thermal loads addressed by the solar energy system vary from those of Schematic Design by more than  $\pm$  ten (10)%. A variation of less than ten (10)% does not warrant the effort necessary to recalculate the array size.

### Collector Layout and Manifolding

After finalizing of the overall collector array size, the designer may proceed to lay out the array for the project, including the manifolding (piping) of the collector rows. The following general parameters shall be followed in the layout of the solar equipment.

- o Locate collector array as close as possible to the mechanical equipment room to minimize piping.
- o Locate storage tank (and drainback tank) as close as possible to mechanical equipment room.
- o Avoid use of underground storage tanks if possible.
- o If collectors are to be roof-mounted, complete layout of rows before plumbing system vents and other roof-mounted equipment are positioned. Coordinate this with responsible mechanical designer.
- o Provide structural engineer with roof loads as soon as possible. Collector weights shall include the weight of water required to fill the array.
- o Request a freeze-proof hose bibb and 120 VAC weatherproof electrical receptacle be installed on roof by responsible mechanical and electrical designers for maintenance.
- o Minimize piping, structural members (collector racks), and plumbing connections (fittings).

The designer should lay out the collector array in a manner that minimizes control requirements. In particular, passive control techniques, such as reverse-return piping, shall be employed instead of flow control valves. Fig. 11 shows a basic array lay-



out using a reverse-return strategy (collectors are plumbed in parallel). Fig. 11a shows a single set of collector rows in an array while Fig. 11b shows a double row arrangement. Selection of a single or double row arrangement is dependent on the following:

- o Number of collectors required,
- o Roof area available, and
- o Roof geometry.

As shown, any unit of fluid will travel the same distance and pass through the same amount of piping regardless of which row the fluid travels through. Friction loss and, therefore, mass flowrate will be the same for all paths, and balanced flow in the array is achieved. The reverse-return piping is shown on the inlet side of array, not the outlet. because during normal operation, the outlet side is hotter than the inlet, and piping is minimized on the outlet side to reduce heat loss.

Reverse-return design is required on all arrays. Most roofs are large enough for reverse-return flow control to be used, although a little effort on the designer's part may be required. Projects in which the size or geometry of the roof makes a reverse-return layout impossible should consider ground-mounting the collector array. Again, a reverse-return layout is required.

If neither a roof-mounted nor ground-mounted array can be designed using a reverse-return layout, the project manager shall reassess the feasibility of the overall solar project. If the solar ener-

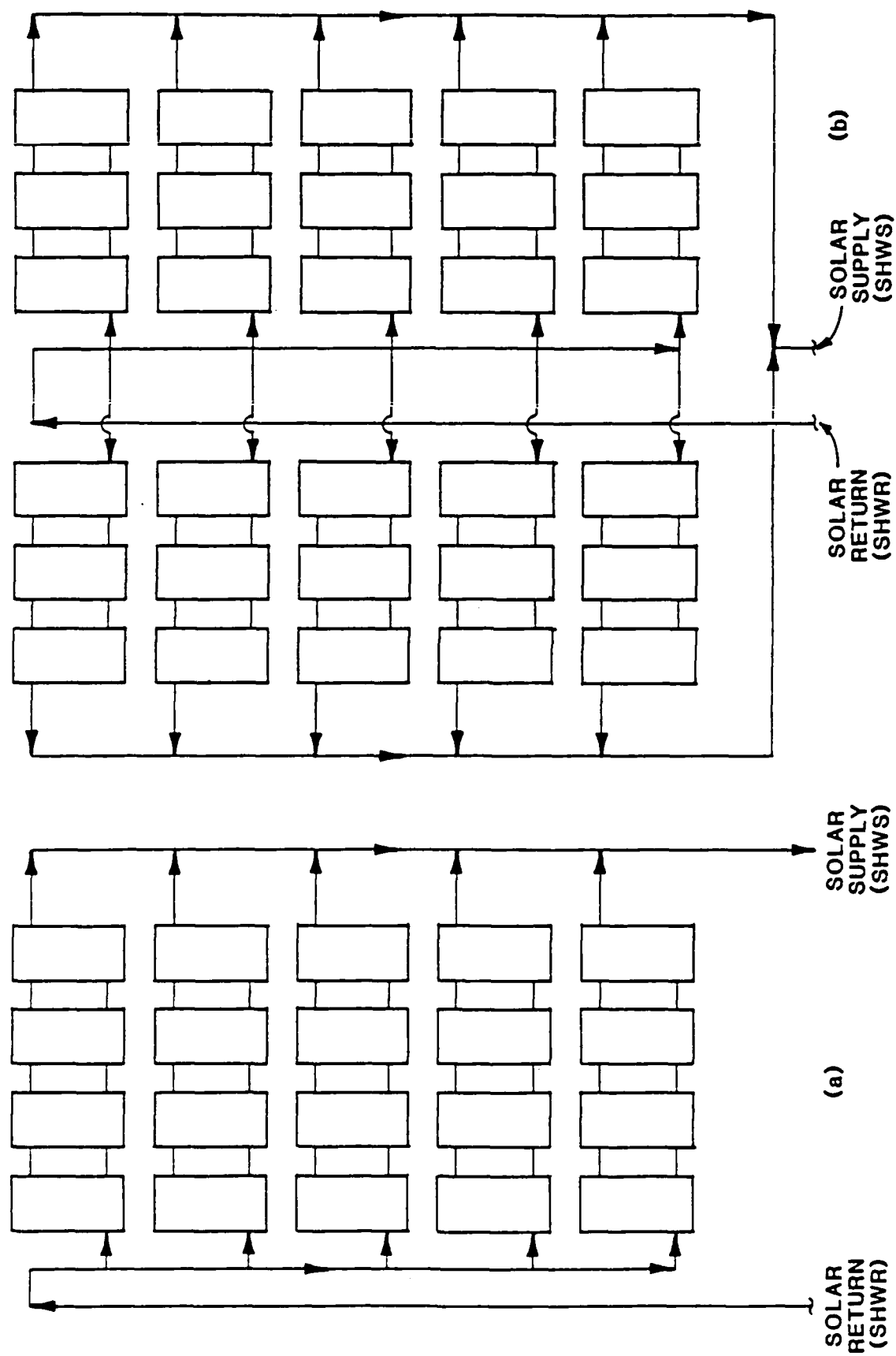


FIG.11 - SIMPLIFIED SCHEMATIC COLLECTOR LAYOUT - REVERSE RETURN

gy system has a minimal return on investment and the reverse-return layout cannot be used, the solar system shall be considered unfeasible and deleted. If the solar system has good payback potential but a reverse-return layout is impossible, the project manager may authorize, in writing, the use of other flow control methods. The written authorization shall certify that the project manager has personally determined that a reverse-return layout cannot be employed in any way.

In these situations, flow control in the array must be accomplished by mechanical flow control devices. It is highly recommended that differential pressure flow control valves (circuit-setters, etc.) be used. These units shall be adjustable for the flow range required by adjusting the valve using a differential pressure meter to determine flow. Once set during start-up, the valve position should be clearly and permanently marked to allow resetting if it is accidentally moved. The differential pressure meter used to set these valves should be a permanent part of the maintenance equipment for the system and should be listed in the contract documents. Fig. 12 shows a single row array using the flow control valves. If flow control devices are used in a drainback system, the designer should insure that they will not impede gravity flow back to the drainback tank.

Many existing systems evaluated have employed flow control devices that are preset, sealed, nonadjustable, one-piece units.

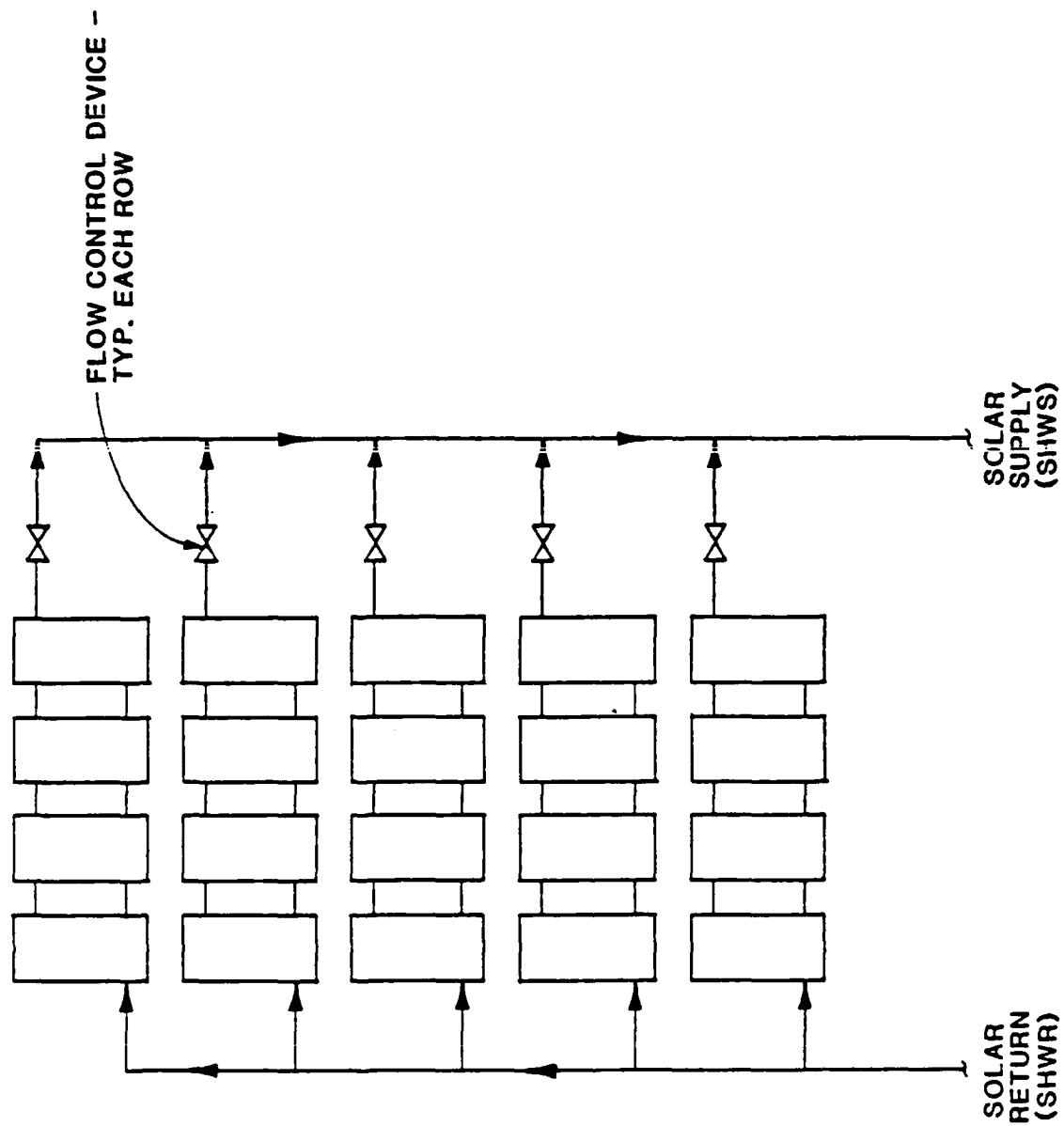


FIG. 12 - SIMPLIFIED SCHEMATIC COLLECTOR LAYOUT - CONTROL VALVE

Although appearing to offer a simple solution, these devices have an inherent problem that has caused a number of system failures. Most of these devices employ an orificed piston and cylinder design to effect flow control. The orifices are quite small and are easily plugged by fine sediment or other suspended particulates in the solar loop fluid. Because they are sealed units, they cannot be inspected or repaired. Use of these flow control devices in a solar energy system requires using filters with very fine mesh (cartridge type) and a meticulous flushing of pipes before installation, resulting in a high maintenance item. This type of flow control device shall not be used in any system.

Concurrent with the layout of the overall array, the designer must also layout the individual rows of collectors because the row design affects the overall layout and vice versa. Fig. 13 shows the layout of a single row of collectors plumbed in parallel. The row is shown complete with valves, sensor, instruments and expansion joints. The collector sensor (for differential controller) need only be installed on one row of the array (closest to mechanical room). An array with several rows of collectors also need not have a thermometer on each; however, each row should have a thermometer well, thereby allowing a single thermometer to be moved from row to row for testing. The thermometer should be installed initially on the same row as the collector sensor.

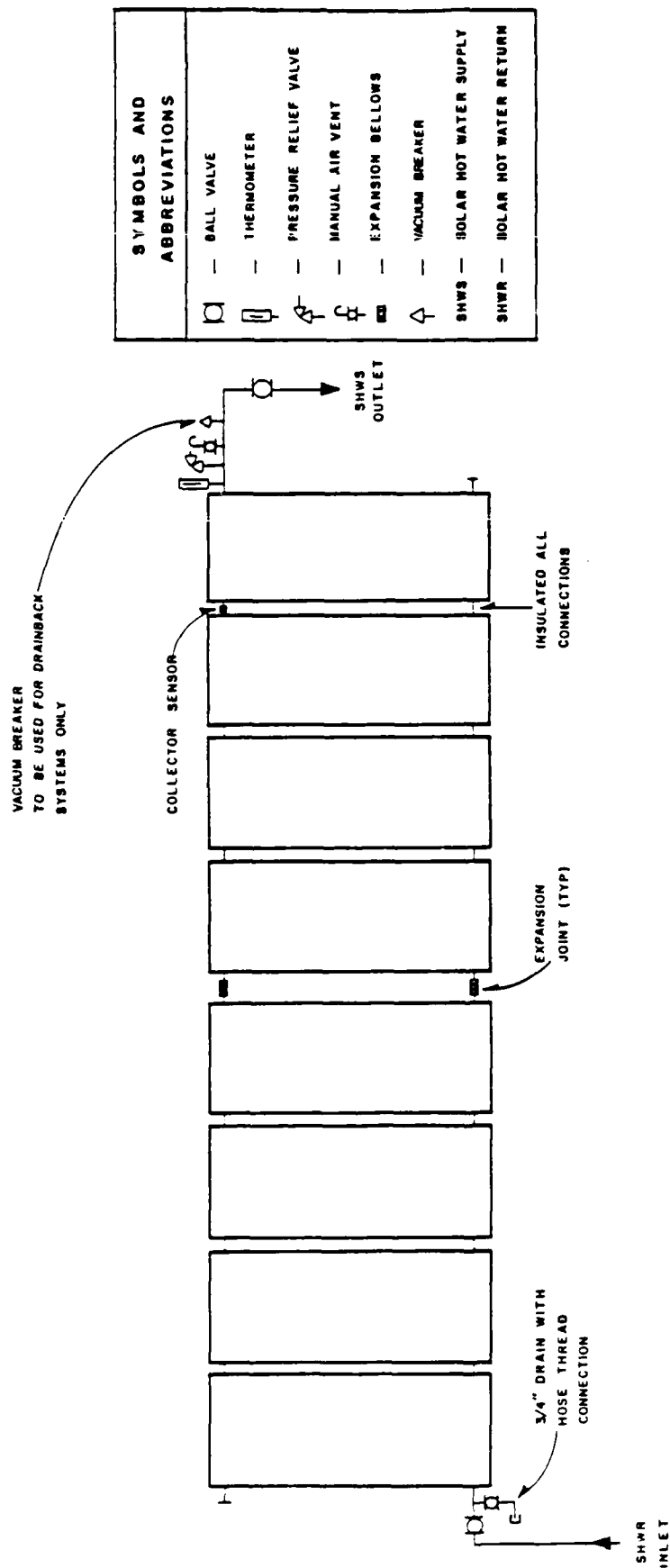







FIG. 13 - COLLECTOR ROW LAYOUT - SINGLE ROW

Fig. 14 shows the layout of a double row array and, in this case, it is set up for a drainback system. A single row drainback would simply be half the row arrangement shown. A double row, non-draining array would also be as shown, except the sloping of the collectors and piping would not be required. All valves and instruments shown, with the exception of the vacuum breaker, would be the same.

In designing the collector rows and the overall array layout, the designer should consider the number of collectors per row. Requirements of this manual call for collectors to be internally manifolded and, therefore, collectors within each row are plumbed in parallel. The number of collectors in each row is determined by the total number required and the size (diameter) of the header pipes. For collectors with a 1.0-inch (nominal) header, the number of collectors per row should not exceed ten (10); for collectors with a header size of 1.25 to 1.50 inches diameter (nominal), the number of collectors per row shall not exceed twelve (12). These limits are imposed to maintain good flow characteristics in the collectors and shall be adhered to. It is also recommended that the designer consult the manufacturers for their recommendations regarding this. See Ref. 8 for a detailed discussion of collector flow characteristics if desired.

ABBREVIATIONS	
SHWR	— SOLAR HOT WATER RETURN
SHWS	— SOLAR HOT WATER SUPPLY

SYMBOLS	
	— BALL VALVE
	— THERMOMETER
	— MANUAL AIR VENT
	— PRESSURE RELIEF VALVE
	— VACUUM BREAKER

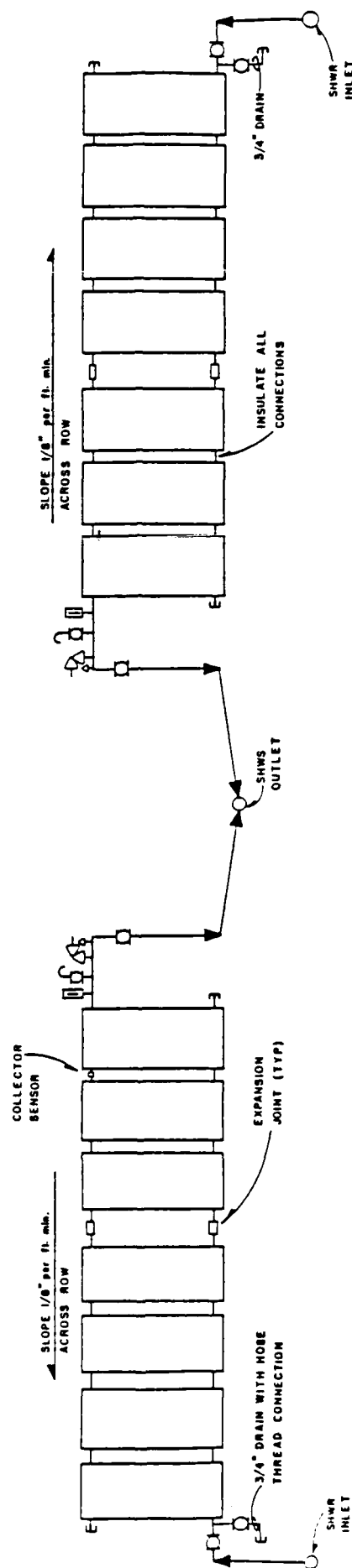


FIG. 14 - COLLECTOR ROW LAYOUT - DOUBLE ROW



### Example

1. Required array area = 2,000 sq. ft. (aperture)
2. Selected collector has 40 sq. ft. aperture area per collector.

Therefore, the number of collectors required is

$$2,000/40 = 50 \text{ collectors.}$$

Selected collector has a header size of 1.5 inch nominal.

Therefore, assuming roof area permits, use five rows of ten collectors each in a single row arrangement.

### Pipe Sizing

Once the collector rows and the overall array layout have been completed, the designer can size the supply/return piping for the solar loop.

Design of the piping system follows the same basic, conventional design methods as those considered generally accepted in plumbing design. (See Ref. 9 and 10 for detailed discussions of piping design if desired). The following general design criteria are to be used:

- o Fluid velocities (water) in piping shall not exceed 5.0 fps.
- o Type "L" copper piping shall be used for all solar loop piping with the exception of indirect swimming pool systems.
- o All solder joints in the solar loop shall be made with silver solder or 95/5 tin/antimony.

Fig. 15 is a graph showing pressure loss and velocity relationships for water flowing in copper tube. Use this graph to determine the appropriate pipe size. In using this graph and selecting pipe sizes, the designer must also consider the overall pipe length (solar loop) and the effect of pipe size on Total System Head (TSH) requirements. Sometimes sizing the piping slightly larger, say 1.5 inch instead of 1.25 inch, can have a significant effect on pump requirements. The increased cost of the larger pipe (and fittings) can be offset by the lower cost of the pump and the lower, long-term operating expense (parasitic power requirements). The effects of various pipe fittings are briefly discussed in the valving and fitting section.

#### Thermal Expansion Control (Piping)

Many of the existing systems evaluated have encountered problems associated with thermal expansion control. Specifically, thermal expansion was not given consideration in the layout of collector arrays and piping systems and the resultant movement of pipe (uncontrolled) caused damage to the system, in some cases terminal. Therefore, all systems designed using this manual shall carefully consider this problem; it shall not be ignored nor left to the installing contractor "to allow for".

The majority of solar energy systems designed using this manual will use copper pipe; therefore, the discussion of expansion control in this section will use copper for all calculations discussed. The rare system using steel pipe will be designed in

# Pressure loss and velocity relationships for water flowing in copper tube

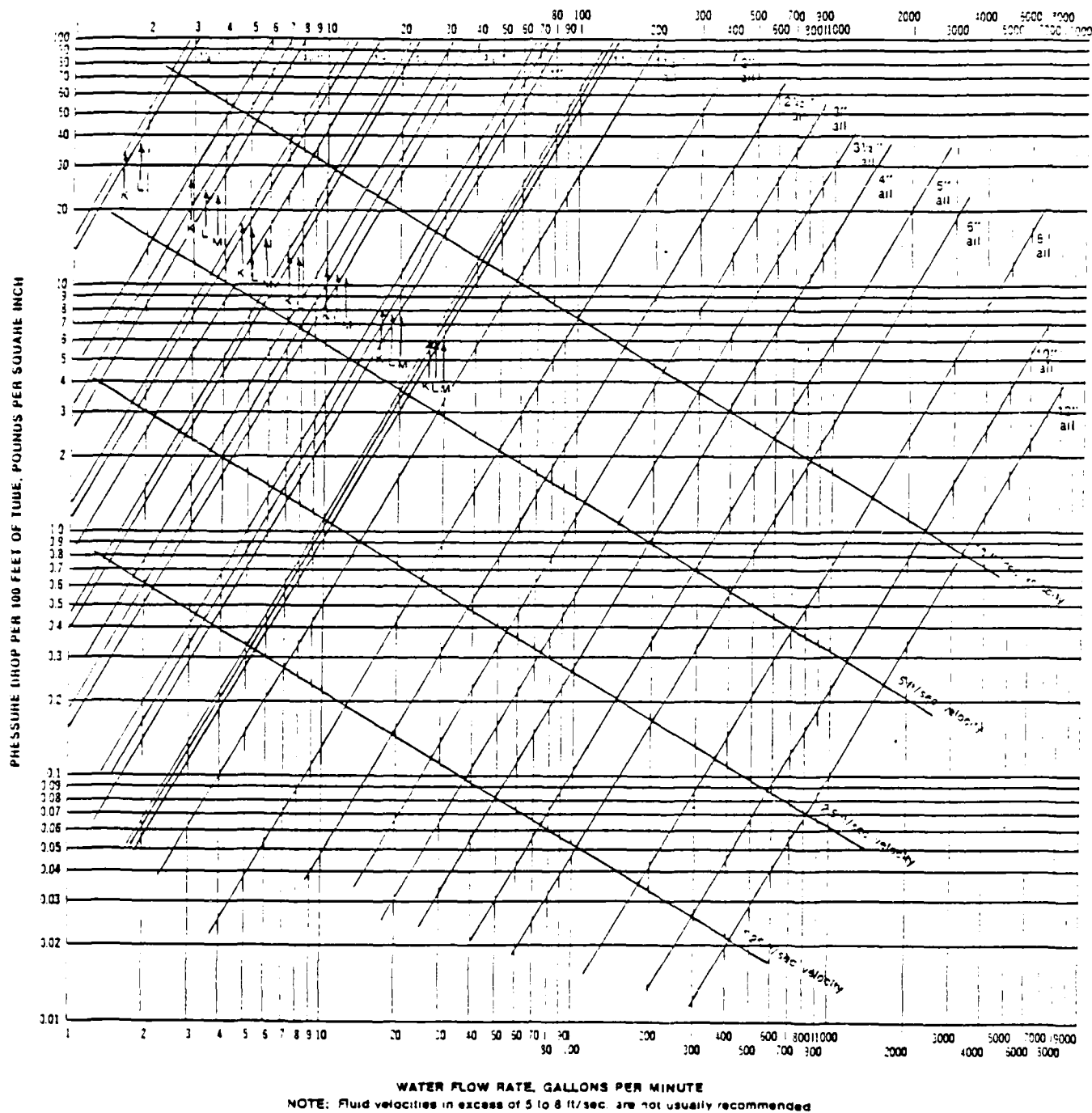


FIG. 15 - PRESSURE LOSS AND VELOCITY RELATIONSHIPS

the same manner but will substitute the expansion coefficients of that material. The same is true for indirect swimming pool systems using PVC or CPVC piping.

Expansion in solar energy system piping is more of a concern than in most other piping systems because of the high diurnal temperature differentials that can be expected. The designer shall base thermal expansion calculations on the largest differential expected. Fig. 16 shows the expansion to be expected in copper tube for a temperature differential range of zero to 350°F, expressed in inches per 100 feet of pipe.

Once a basic equipment layout is completed, the designer shall analyze each section of piping for expansion control requirements. Obviously, some basic engineering judgment is necessary here; expansion in short runs of pipe can be accommodated in elbows normally occurring between equipment. Particular attention should be paid to piping involving pumps and collectors; shifts in pump alignment caused by the uncontrolled thrust of expanding pipe can cause significant damage in a short period to a pump (bearings, seals, etc.).

#### Collector Row Expansion

Assembly of internally manifolded collectors in rows results in the top and bottom headers becoming long, straight runs of pipe. For example, eight 4.0 ft. wide collectors in a row, with a 4.0 in. spacing between each, results in a set of continuous headers

Expansion (per 100 feet) vs. temperature change for copper tube

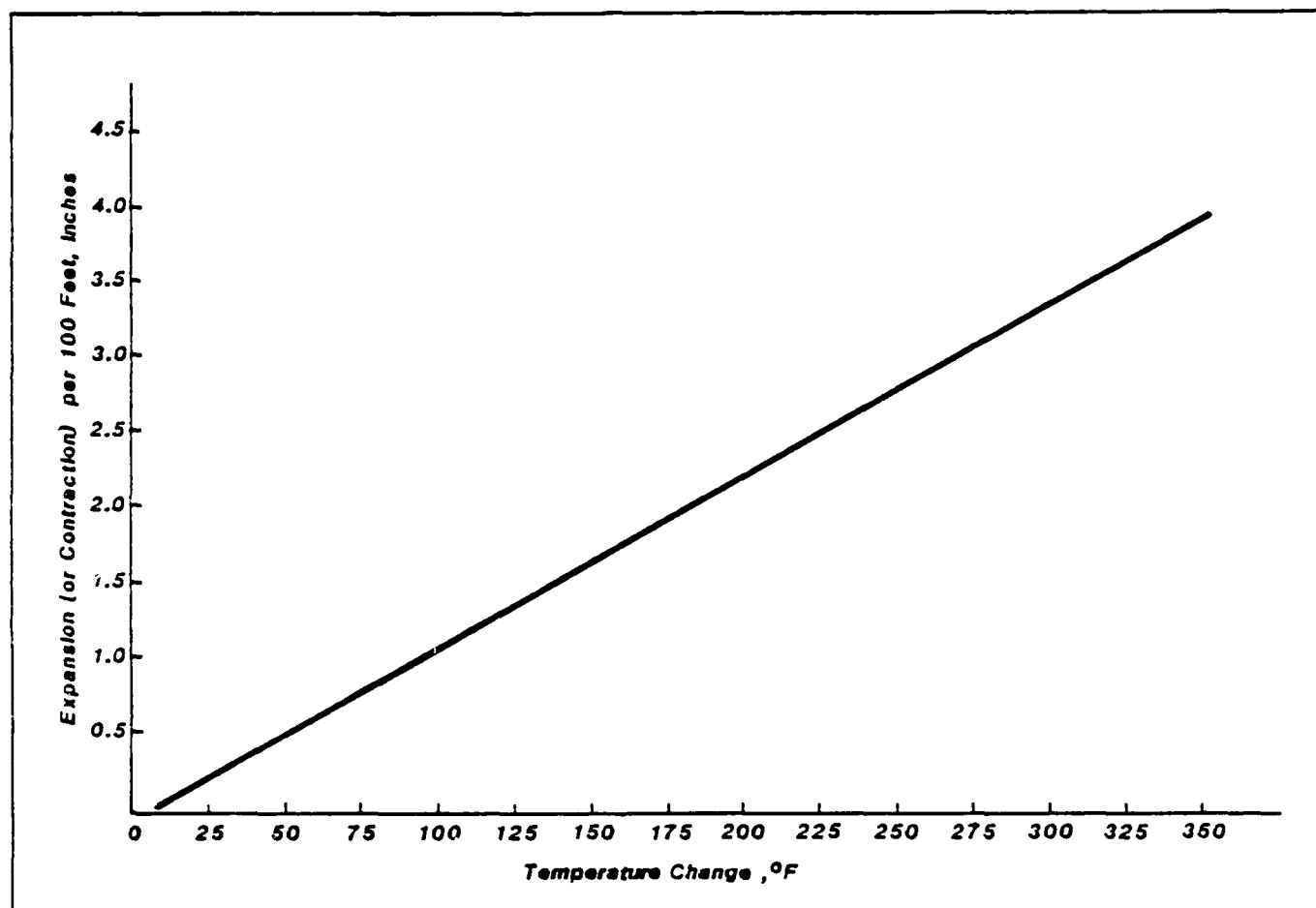


FIG. 16 - PIPE EXPANSION AS A FUNCTION  
OF TEMPERATURE DIFFERENTIAL

approximately 40 ft. long for each row. If the design temperature differential is 150°F, the expansion to be expected is roughly 0.6 inch, a significant amount, as calculated using Fig. 16.

Expansion should be absorbed by anchoring each end of the collector row and absorbing the expansion near the mid-point. Fig. 14 and 15 indicate an expansion joint (bellows type) installed between the middle two collectors. In the example above, this unit would be selected to accept 0.6 inches of expansion. Field-constructed expansion loops could also be used, although they will add more to the overall length of the row than the bellows. Expansion loop construction is discussed in the next section. Bellows used for expansion control in this manner should be metal of the same type as the collector headers and designed to expand and contract in-line with the pipe. Do not use nonmetallic hose with hose clamps for this purpose.

An alternate method for expansion control in the collector row is to anchor the middle point of the row and absorb half the calculated expansion at each end using flexible metallic hose with solder type fittings.

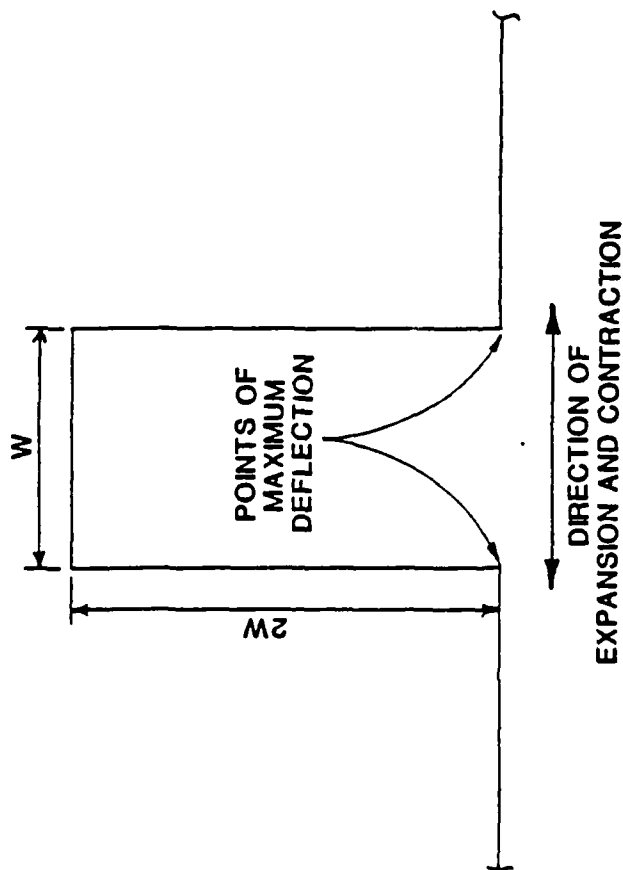
In both cases, the collectors themselves (absorbers and headers) are moving laterally on the support rack. Absorbers that are rigidly attached to the collector box shall not be used.

## Pipelines

Expansion in the various pipeline segments is calculated according to the length of pipe between pieces of equipment or anchor points. These calculations should be made as soon as the basic system is laid out so that space for expansion control loops can be allocated and proper valving can be installed later. The following points shall be followed in expansion control design:

- o Assume the worst case temperature differential for design.
- o Avoid design of expansion control that will trap air or prevent draining of array (even for closed-loop system).
- o Give preference to anchoring corners and absorbing expansion at the midpoint where feasible.  
Anchoring the midpoint and expanding at the ends is acceptable, if necessary, but more troublesome than the former method.
- o Provide guides as well as anchors to control the direction of expansion.

Once actual expansion has been calculated, the expansion loops and/or expansion joints can be selected and designed. Fig. 17 shows a standard, field fabricated expansion loop that is sized according to the specific application. As shown, the depth of



**NOTES:**

1. DEPTH OF LOOP SHALL BE APPROXIMATELY EQUAL TO TWICE THE WIDTH OF THE LOOP.
2. DEVELOPED LENGTH DL, EQUALS THE SUM OF THE WIDTH PLUS BOTH SIDES OF THE LOOP.  

$$DL = 2W + 2W + W \text{ OR } 5W$$
3. DO NOT ANCHOR SIDES (2W) OF LOOP OR INTERFERE WITH PIPE MOVEMENT AT POINTS OF MAXIMUM DEFLECTION.
4. SEE TABLE IV FOR DETERMINATION OF DEVELOPED LENGTH

**FIG. 17 - EXPANSION LOOP SIZING, FIELD FABRICATED**



TABLE V

## DEVELOPED LENGTH OF EXPANSION LOOPS

Expected Expansion, Inches	.25	.375	0.5	0.75	1.0	1.25	1.5	2.0	2.5	3.0	3.5	4.0	5.0
0.5	38	44	50	59	67	74	80	91	102	111	120	128	142
1.0	54	63	70	83	94	104	113	129	144	157	169	180	201
1.5	66	77	86	101	115	127	138	158	176	191	206	220	245
2.0	77	89	99	117	133	147	160	183	203	222	239	255	284
2.5	86	99	111	131	149	165	179	205	227	248	267	285	318
3.0	94	109	122	143	163	180	196	224	249	272	293	312	348
3.5	102	117	131	155	176	195	212	242	269	293	316	337	376
4.0	109	126	140	166	188	208	226	259	288	314	338	361	402

the expansion loop should be approximately twice the width of the loop because the actual expansion and contraction is absorbed in these legs. The overall developed length (DL) of the loop where

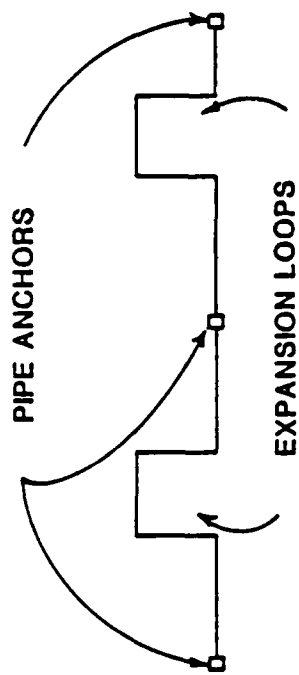
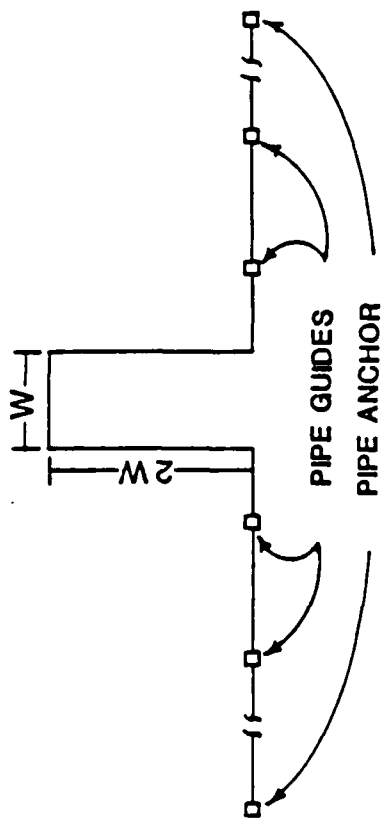
$$DL = 2W + 2W + W \text{ or } 5W$$

is determined from Table V once the actual amount of expansion is known.

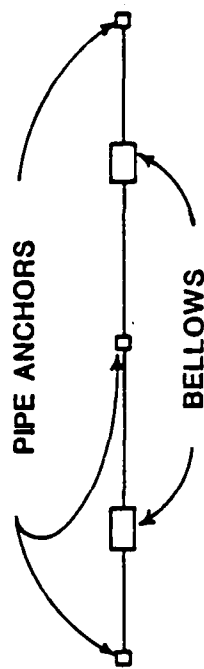
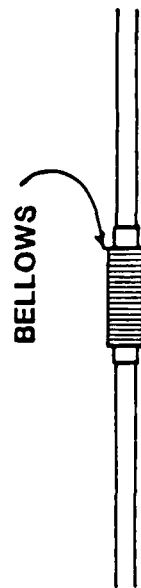
Once the expansion loop is designed and located in the array piping, the designer must ensure that pipe guides, supports, and anchors are designed and located such that the expansion loop can perform its intended function; expansion and contraction must be absorbed at the expansion loop. Do not place anchors where guides should be.

Fig. 18 shows schematically the layout of expansion loops and expansion joints in relation to pipe guides and anchors for both single and double installations. Double loops and/or joints are used where there is insufficient room for a single loop or where expansion is greater than a single joint can accept. Note that a pipe anchor must be placed midway between two loops or joints in the same pipe section.

Pipelines must also be supported throughout the array. Extra care must be taken with this item for drainback systems to ensure that the proper slope is maintained and no low points exist in the piping. Minimum requirements for piping supports are as follows:



### EXPANSION LOOP DETAIL-FIELD FABRICATED



### EXPANSION JOINT DETAIL-MANUFACTURED JOINT

FIG. 18 - EXPANSION LOOP/JOINT DETAILS

Vertical: Secure at sufficiently close intervals, but not more than 10-foot intervals, to keep pipe in alignment and carry the weight of the pipe and contents.

Horizontal:

Screwed pipe-maximum support interval shall be 10 feet.

Copper tube - support copper tube at a maximum interval of six feet for tube diameters of 1.5 inch and smaller, and at a maximum interval of 10 feet for tube diameters of 2.0 inches and larger.

### Fluid Expansion

The solar energy systems described in this manual include both open and closed loop systems. Open loop systems in which the heat transfer fluid is drained from the collector array need not be addressed when considering fluid expansion control. During normal operation, fluid expansion in these systems is handled inherently by the system in the following manner:

1. Fluid expansion is absorbed in the atmospheric (unpressurized) drainback tank.
2. Excessive pressure at the collectors, if it occurs, is released through the PRV at each collector row.

Closed loop systems that use only water as the heat transfer fluid (direct recirculation) must address fluid expansion but only in the normal operating range ( $\leq 180^{\circ}\text{F}$ ); expansion control need not be designed to handle stagnation. Stagnation-generated pressures are handled by the PRVs, and lost fluid is replaced through automatic water make-up valves.

Fluid expansion control becomes a critical design issue, however, when addressing closed loop systems using water/glycol mixtures for the heat transfer fluid. Reasons for this are twofold:

1. Glycol mixtures and the related maintenance labor to replace mix lost through PRV venting are high cost items.
2. If lost fluid is not replaced with the proper water/glycol mixture (normally 50/50), freeze protection will be reduced or lost, and system damage may occur.

The majority of existing, closed loop glycol systems examined in the field were operating at a rough average of 10% glycol instead of 50% because of make-up of lost fluid with water only. Also, many nonoperational systems were caused by lack of fluid.

Standard calculations, shown in this manual are available for determining the proper size of system expansion tanks. However, standard procedure is to size the expansion tank for normal

operating conditions only: stagnation temperatures and pressures are not considered. For non-glycol, closed loop systems this is the proper procedure, and stagnation conditions are handled by venting through the PRV. This is not the case for closed loop glycol systems. Glycol systems should have expansion tanks designed to handle fluid expansion at stagnation conditions.

### Sizing Procedure

The equation for sizing expansion tanks is as follows:

$$V_t = (0.00041T - 0.0466) V_s / (P_a/P_f - P_a/P_o)$$

where,

$V_t$  = minimum expansion tank volume, gallons

$V_s$  = system volume, gallons

$T$  = maximum average operating temperature, °F

$P_a$  = pressure in expansion tank when water first enters, ft. of water-absolute

$P_f$  = initial fill or minimum pressure at tank, ft. of water-absolute

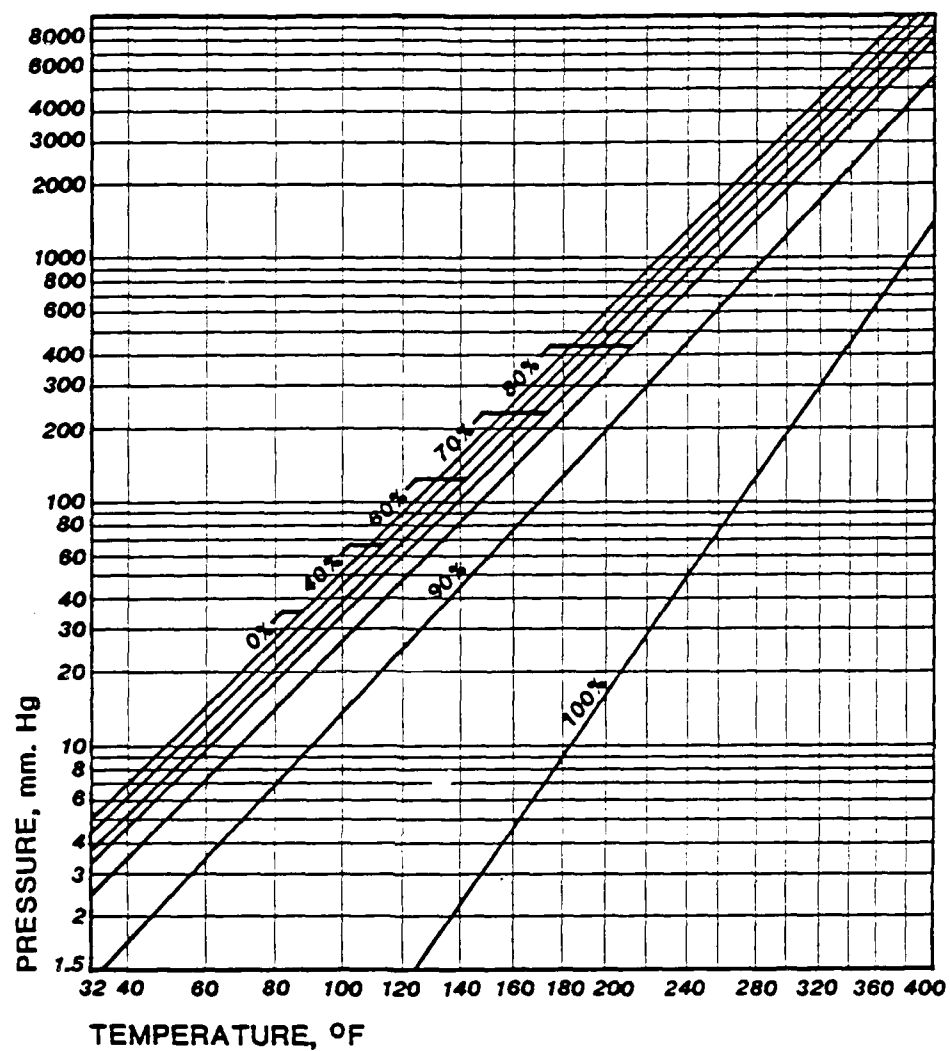
$P_o$  = maximum operating pressure (including pumping head) at tank, ft. of water-absolute.

For closed loop, non-glycol systems, the values for equation variables should be determined for normal operating conditions, as stated previously. For example, the normal operating conditions for a direct recirculation system would probably be ambient

temperature to 180°F, based on upper limit temperature control settings. Therefore,  $P_0$  would be the pressure of water at a temperature of 180°F plus pump pressure.

For calculation of the expansion tank size for closed loop glycol systems, design conditions should be chosen for stagnation. That is, system temperatures during stagnation (no flow) can approach 300°F for the type of flat-plate collector required by this manual. Therefore, the maximum pressure variable,  $P_0$ , in the equation should be set for the pressure of the water/glycol mix at this point (see Fig. 19). As shown in Fig. 19, the vapor pressures of water/glycol mixes are slightly lower than those for water, and the designer may, if desired, use standard steam tables for a slightly more conservative design. Consult Ref. 11 for a more detailed discussion of water/glycol mixes if desired. Pump pressure need not be added to this because the pump is inoperative at this time. System control logic should not allow pump restart until collector temperatures drop below the upper limit setting (normally 180°F).

System volume is calculated by summing the volumes of all piping and equipment in the loop, including the collectors and heat exchangers. Physical data for various types and sizes of pipe are contained in Ref. 9 and 10. If necessary, approximations can be made for piping volume. The initial pressure variable,  $P_f$ , will vary depending on system type and fill procedures. A direct recirculation system operates at incoming water service pressure,



PROPYLENE GLYCOL/WATER MIXTURE BY WEIGHT

FIG. 19 - VAPOR PRESSURE CURVES - WATER/GLYCOL MIXTURES



normally around 60 psig unless pressure reducing valves are used. For glycol mixtures this pressure should be equal to the output pressure (discharge) of the fill pump (which can be the solar loop pump) but should not be less than the vapor pressure of the water/glycol mixture at ambient conditions.

$P_o$ , the maximum operating pressure, should be equal to the corresponding fluid pressure at

- o Nonglycol = normal operating temperature.
- o Glycol mix = stagnation temperature.

For nonglycol systems,  $P_o$  should not exceed the PRV release pressure.

$P_a$ , the pressure in the expansion tank when water first enters, will normally be atmospheric pressure at the location.

Expansion tank size for large systems ( $\geq 1000$  gal.) operating at  $P_a$  = atmospheric pressure can also be determined by using the nomograph of Fig. 20.

Instructions for use of this nomograph are as follows:

1. Extend a line from the value of  $P_o$  through the value of  $P_f$  to reference line 1.
2. From this point extend a line through the value of  $T$  to reference line 2.

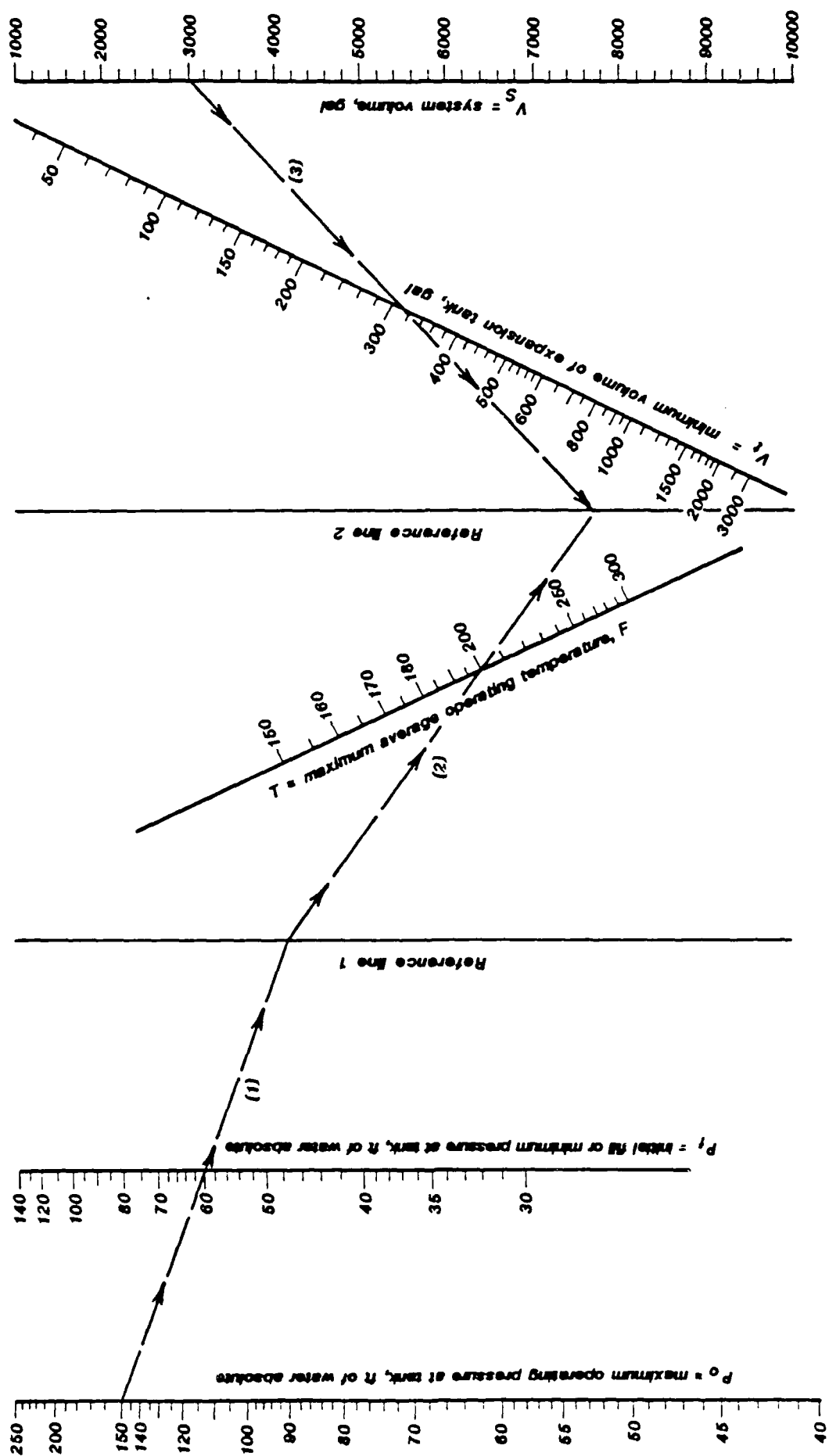


FIG. 20 - NOMOGRAPH FOR EXPANSION TANK SIZING

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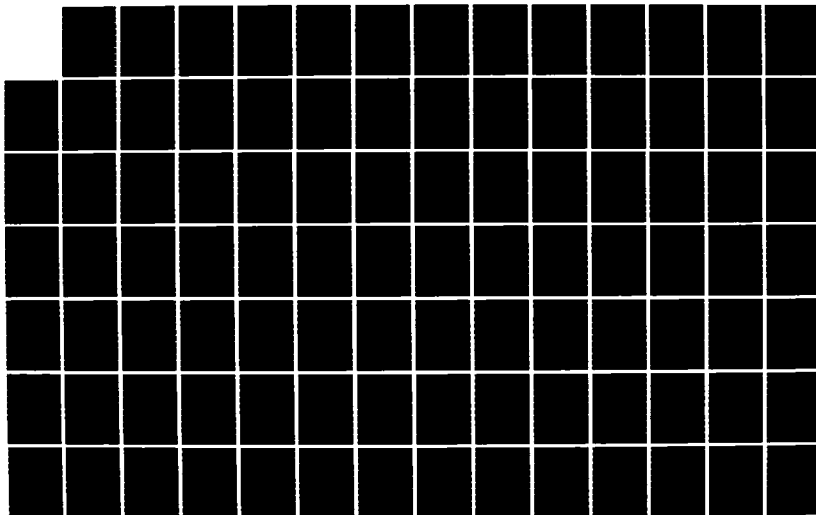
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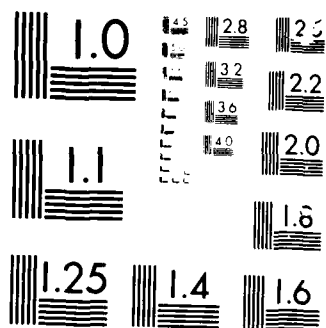
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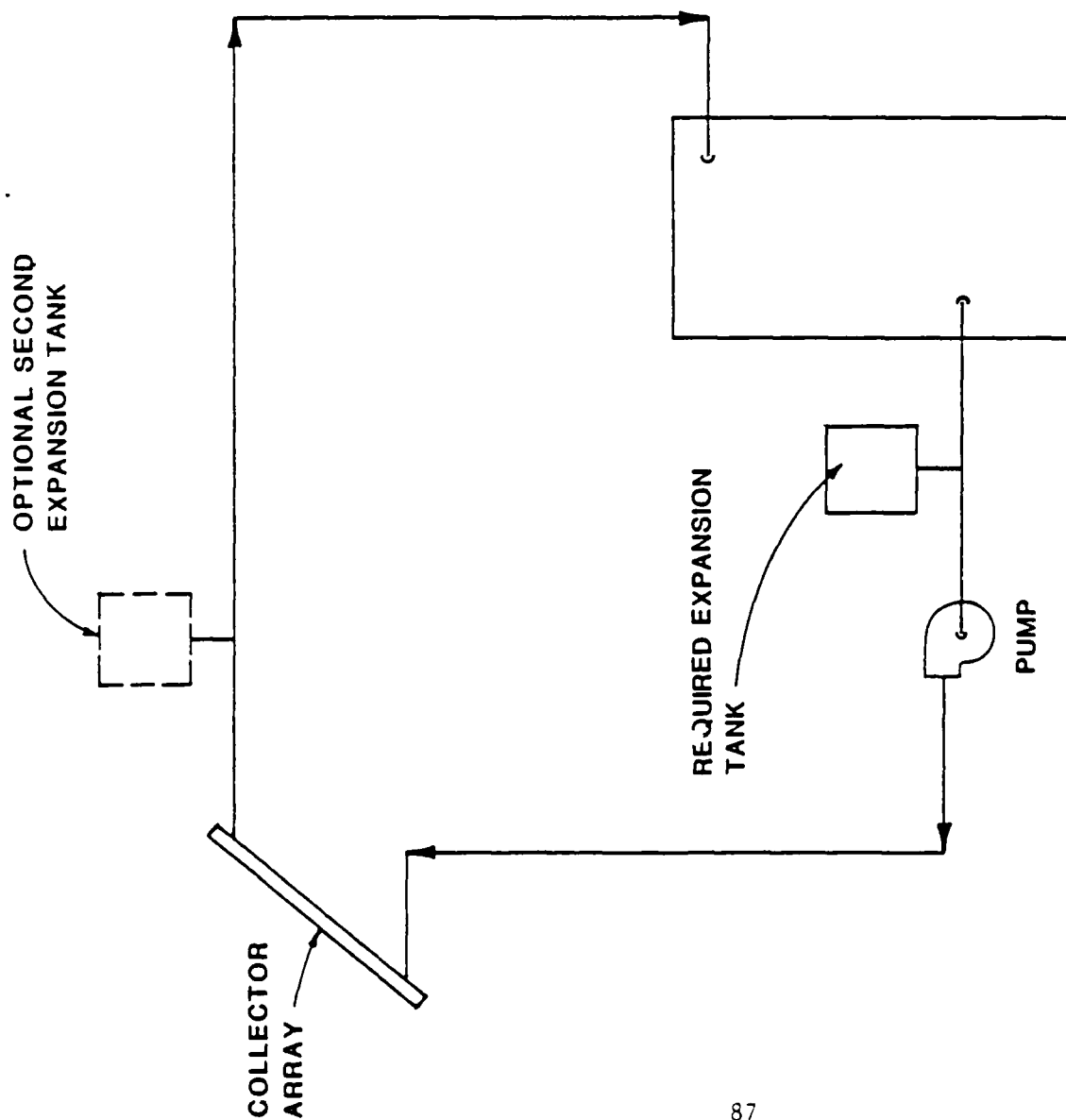
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3. From this point on reference line 2, extend a line to the value of  $V_s$ .
4. Read the value of  $V_T$  where this line crosses the  $V_T$  scale.

Standard procedure for expansion tank design normally incorporates a safety factor increase in size of 10 to 50%. A safety factor of 20-25% should be used for this manual. Therefore, expansion tank volumes calculated should be multiplied by 1.20 or 1.25 for final sizing.

Location of the expansion tank in the system is also important. The tank should be located on the suction side of the solar loop pump. This location will help prevent pump cavitation. It is also acceptable to design two separate expansion tanks for use in closed loop glycol systems in which the collector array is a significant distance from the mechanical room. The primary expansion tank would be in the mechanical room on the suction side of the pump and sized for the normal operating range of the system. The secondary expansion tank would be at the collector array (outlet side) and sized for the difference between normal operation and stagnation point expansion. Fig. 21 is a simple schematic for both a single and double tank system.

Expansion tanks used in these solar systems shall be the type using internal bladders. These bladders should always be constructed of EPDM rubber to withstand the high temperature



NOTES:

1. ALWAYS INSTALL EXPANSION TANKS ON THE SUCTION SIDE OF THE PUMP.
2. IF A HEATING UNIT (BACK-UP) IS INVOLVED, INSTALL EXPANSION TANK ON THE OUTLET SIDE OF THE HEATER.

**FIG. 21 - EXPANSION TANK LOCATIONS**

experienced during system stagnation. The majority of systems can be handled by off-the-shelf expansion tanks. When the expansion tank required is larger than those available with bladders, use two or more expansion tanks of equal size instead of a single custom built tank without a bladder.

As shown in Fig. 21, a PRV is required as part of the expansion tank system. The pressure release setpoint of the PRV should be higher than the pressure generated by the fluid at stagnation but lower than the allowable working pressure of the system. Most (not all) flat-plate collectors are rated at 125 psig, while a 50% glycol mix generates roughly 80 psig at 300°F. Therefore, a recommended PRV setting would be 100-110 psi. PRVs installed on collector rows should be set at the same point. Ref. 9 and 12 may be studied if the designer wishes a more detailed analysis of expansion tank systems.

### Storage Tank and Piping

Most of the system designs in this manual require the use of a pressurized storage tank for solar storage. The drainback system uses an open, vented drainback tank with a pressurized storage tank, while the swimming pool systems use the swimming pool itself for storage.

Design of a pressurized storage tank is more a case of selecting a tank than actually designing it. Most tank manufacturers provide catalogs or data sheets for the various stock tanks they

produce. The system designer should use an off-the-shelf product as a matter of practice to minimize cost. The majority of stock pressure vessels sold come in a variety of sizes and configurations for the same volume. For example, a 2,000 gallon tank could be obtained in a 6.0 ft. diameter by 10.0 ft. long tank, an 8.0 ft. diameter by 6.0 ft. long tank, or a 4.0 ft. by 22.0 ft. tank. Obviously, a 4.0 ft. x 22.0 ft. tank is not appropriate and a certain amount of engineering judgment should be used. The following selection criteria should be used in selecting a storage tank for the system:

1. Use "stock" pressure vessels. Do not require a custom-built tank to meet an exact storage volume. A 1,920 gallon custom-built tank can be replaced with a 2,000 gallon off-the-shelf unit that will do just as well.
2. The designer should select a tank with a length-to-width ratio as close to 2:1 as possible. Availability of sizes and mechanical room space will greatly affect this.
3. Tanks should be vertically mounted if possible. This, coupled with the second criterion will take advantage of natural stratification to slightly enhance overall system performance.
4. All pressure vessels shall have an access manway for maintenance.



5. All pressurized tanks shall be constructed to meet ASME pressure vessel code and shall be stamped with an ASME pressure vessel stamp where required.
6. All pressurized steel tanks shall be lined with nontoxic, low soluble cement to a thickness of 0.25 to 0.375 inches.  
The cement shall have the same coefficient of expansion as the steel shell.

The most crucial item for the solar storage tank, especially pressure vessels, is the size and location of piping and instrument penetrations. Most tank manufactures allow options in penetrations for their stock tanks. The following criteria shall be used in tank penetration selection:

1. Tank penetrations for solar supply and return shall be the same size as the supply/return piping or larger.
2. Separate penetrations for a manual tank drain and pressure relief shall be included.
3. A minimum of two temperature sensor wells, in addition to visual thermometer wells, shall be required. One sensor well shall be near the top and one near the bottom.

4. All tanks shall have penetrations for installation of a visual level gauge. The level gauge should cover at least the top half of the tank.

The piping for both the solar loop and the load interface should be such that short-circuiting between supply and return be avoided. Fig. 22 shows the arrangement for supply and return loops for both a vertical and horizontal tank. As shown, the arrangement of the supply and return loops prevents hydraulic short circuits from occurring. The hottest fluid is also delivered to the top of the tank by the solar loop and removed from the top by the load loop; the coldest fluid is sent to the collectors from the bottom of the tank.

#### Valving and Fittings

Valving of the system is an important but often neglected area of design for the solar energy system. The most important functions of valves are the following three areas:

1. Isolation of equipment for scheduled maintenance or replacement;
2. Flow control, manual or automatic; and
3. Protection, including manual and/or automatic venting or draining.

FROM SOLAR

TO LOAD

FROM LOAD

TO SOLAR

FROM SOLAR

TO LOAD

TO SOLAR

FROM LOAD

FIG. 22 - STORAGE TANK PIPING SCHEMATIC

It is necessary to locate and select the type of the majority of valves before the system pump can be sized because of the friction losses (head) associated with various valves. Obviously, this does not apply to valves in normally nonflowing lines such as pressure relief, drains, or vents.

The following equipment shall be equipped with valves for isolation:

- o Collector rows,
- o Pumps,
- o Storage and/or drainback tanks,
- o Heat exchangers,
- o Backup heaters,
- o Expansion tanks,
- o Instruments and gauges (not necessary for instruments installed in wells),
- o Make-up water systems, and
- o Strainers and/or filters.

The following equipment shall be equipped with valves for flow control and draining:

- o Solar loop pump (flow control),
- o Collector rows (drain),
- o Storage and/or drainback tanks (drain),
- o Collector supply/return loop (fill & drain), and
- o Expansion tanks (drain).

The following equipment shall be equipped with valves for protection:

- o Collector rows - pressure relief valve (PRV),
- o Storage tank - PRV at top and pressure/temperature relief valve (PTRV) for overtemperature draining, and
- o Any other heat producing equipment.

The isolation valves on the various pieces of equipment are primarily for isolating the equipment without draining the system, for maintenance or replacement. Ball valves should be used for this application as well as the filling and draining applications. It can be determined at a glance, whether a ball valve is opened or closed. In addition, ball valves have extremely short stems compared with other types of valves, and heat loss from the exposed stem surface is minimized.

Table VI indicates the various general types of valves and their most applicable functions. This table is not intended to dictate valve function but to provide a guide for selection. Concurrent with the use of Table V, the designer must consider the pressure loss associated with various types of valves and fittings and their effects on pump sizing. Table VII lists the equivalent lengths in pipe diameters for the various valve types and fittings used. As shown, selection of valve types can cause significant variations in total pressure drop and directly affect pump selection.

Particular emphasis should be paid to valving of the solar loop pump. This pump should be valved for the throttling function first and the isolation function second. All solar loops should include a visual flowmeter to determine the approximate flow-rate. A throttling valve should be used to allow adjustment of the solar loop pump output.

Fittings within the systems should specifically include the use of dielectric unions wherever dissimilar metals are joined in the fluid system. This includes pumps, valves, other fittings and piping.

#### Pump Selection

Selection of a pump (solar loop) is a key issue in the design process but must, of necessity, be one of the final items accomplished. To properly select a pump the designer must have the following information:

- o Required flowrate,
- o Complete system piping layout,
- o Operating temperature, and
- o Fluid characteristics.

Selection of a pump is based primarily on the first two items above, assuming the following:

1. Operating temperatures are not extreme. Because this manual does not address high temperature systems, this is not an issue.

**TABLE VI**

## VALVE TYPES AND FUNCTIONS

FUNCTION	BALL	BUTTERFLY	CHECK	GATE	VALVE TYPE GLOBE OR CONE	PLUG COCK
BACK FLOW			X			
STOPPING FLOW	X	X		X	X	X
THROTTLING	X				X	X

TABLE VII  
EQUIVALENT LENGTH IN PIPE DIAMETERS OF VALVES AND FITTINGS

VALVE	DESCRIPTION	EQUIVALENT LENGTH IN PIPE DIAMETERS
Globe	Stem Perpendicular to Run With no obstruction in flat, bevel, or plug type seat With wing-or pin-guided disc	Fully open 340 Fully open 450
Valves	(No obstruction in flat, bevel, or plug type seat) - With stem 60 degrees from run of pipe line - With stem 45 degrees from run of pipe line	Fully open 175 Fully open 145
Angle Valves	With no obstruction in flat, bevel, or plug type seat With wing-or pin-guided disc	Fully open 145 Fully open 200
Gate Valves	Wedge, Disc, Double Disc, or Plug Disc Fully open Three-quarters open One-half open One-quarter open	13 35 160 900
Pulp Stock	Fully open Three-quarters open One-half open One-quarter open	17 50 260 1200
Conduit Pipe Line Gate, Ball and Plug Valves	Fully open	3*
Check Valves	Conventional Swing Clearway Swing Globe Lift or Stop; Stem Perpendicular to Run or Y-Pattern Angle Lift or Stop In-Line Ball 2.5 vertical and 0.25 horizontal	135 50 Same as Globe Same as Angle 150
Foot Valves with Strainer	With poppet lift-type disc With leather-hinged disc	420 75
Butterfly Valves (8-Inch and larger)	Fully open	40
Cocks	Straight-Through Rectangular plug port area equal to 100% of pipe area	Fully open 18
Three-Way	Rectangular plug port area equal to 80% of pipe area (fully open) Flow straight thru Flow thru branch	44 140



Fittings	90 Degree Standard Elbow	30
	45 Degree Standard Elbow	16
	90 Degree Long Radius Elbow	20
	90 Degree Street Elbow	50
	45 Degree Street Elbow	26
	Square Corner Elbow	57
	Standard Tee	20
	With flow through run With flow through branch	60
	Close Pattern Return Bend	50

\* Exact equivalent length is equal to the length between flange faces or welding ends.

2. The operating fluid is either water or water/glycol mixture. If other fluids were used, such as heat transfer oils (not allowed in this manual), fluid viscosity as a function of temperature would be critical.

System flowrate was determined based upon array size in a prior section. Valving, piping, and layout have also been addressed. At this point, the designer must calculate the TSH in feet of water that must be handled by the solar loop pump, including both static and dynamic (friction loss) head.

The dynamic head is calculated by summing the friction losses and/or pressure drops associated with all the equipment (collectors, tanks, etc.), piping, valves, and fittings in the system. The static head is calculated by determining the difference between the static discharge head required and the suction head available to the pump.

Systems covered in this manual are basically of two types: open loop and closed loop. In an open loop system, the static head is a critical issue because the pump must overcome the static head requirement each time the pump is activated. For example, an open loop system with the collector array 40 feet above the pump and storage tank must overcome the 40 ft. head each time the pump is activated, whereas the same system in a closed loop need only address the dynamic head because the vertical piping remains full during pump off periods. The designer should note that the sta-

tic head is an open loop system that must be overcome but need not be overcome at the design flowrate. Once the system (piping) is full, the static head drops off, and the system operates like a closed loop. Therefore, the pump must only handle the static head initially.

Once the flowrate and head requirements are established, a specific pump can be selected. The following parameters are also recommended in actual selection:

- o Centrifugal pumps should be used wherever possible.
- o All wetted surfaces should be brass, bronze, or stainless steel.
- o End-suction, close-coupled preferred but not required.
- o Staging (series flow) of pumps is acceptable and has the advantage of redundancy but at slightly higher initial cost.

Staging of pumps is an acceptable standard practice and has certain advantages and disadvantages over single pump systems. Dual pumps provide a measure of reliability to the system (redundancy) that should be considered. A two-pump system allows the solar loop to continue flowing if one pump fails (normally at half the design flowrate), and stagnation can be avoided. The disadvantages to a dual pump system are higher initial cost and possibly higher maintenance cost.

If a dual pump system is used, each pump should be capable of pumping roughly half the design flow at the TSH required. If neither of the two pumps working alone can overcome the TSH at reduced flow, there is no gain in reliability with two pumps.

Both pumps should be controlled by the same signal. That is, both pumps should be activated and deactivated at the same time. Do not complicate the control logic by controlling one pump with one set of conditions and the second pump with a different set of conditions. Keep the controls as simple and straightforward as possible.

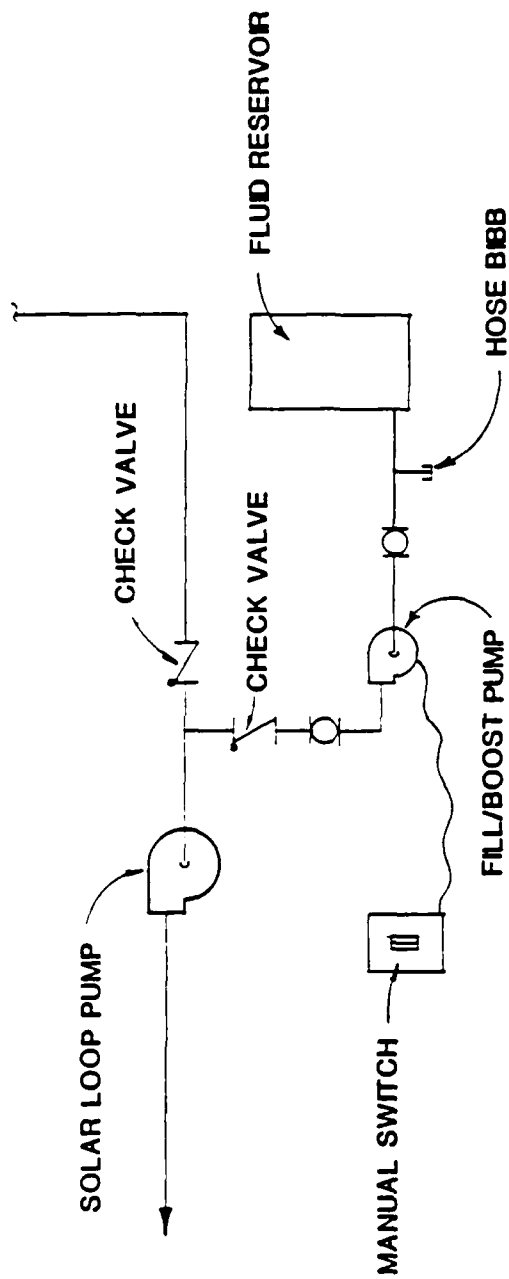
As stated, pumps for closed-loop systems can be sized for the dynamic head of the system source once they are filled. The static head need not be addressed. An additional aspect is that the initial filling of the system or refilling after manual draining for maintenance. If the selected solar loop pump is not capable of overcoming the static head (It need not be at the design flowrate), a booster fill pump should be designed into the system. This pump should be a low-flow, high-head pump sized to just overcome the static head of the system for filling. Providing a connection for a pump to be brought to the site and connected to the system for the sole purpose of filling is possible but time-consuming and actually more costly (maintenance time) than having a permanent fill booster pump.

Fig. 23 shows schematically the layout for a fill booster pump. As shown, the booster pump is installed on the suction side of the solar loop pump. In this arrangement, the booster pump must provide only the difference between the static head of the system and the static head that the solar loop pump is capable of providing itself. For example, a closed loop glycol system has a static head of 50 ft., and the selected solar loop pump is capable of producing 25 ft. of head at some fraction of the design flowrate. Therefore, the fill booster pump should be sized to provide a minimum of 25 ft. of head at that flowrate. In this case, the booster pump is simply increasing the positive suction head to the solar loop pump.

Controls for the fill booster pump should be manual only, as it is only used occasionally for filling the system. Also, as shown in the schematic, a small tank for the solar loop fluid is desirable (55 gal. drum or similar container) but is not required if space is at a premium. In this case, a drum of premixed fluid can be brought in for this purpose and then removed.

### Heat Exchangers

All but two of the systems described in this manual require a heat exchanger on either the solar loop or load loop. Proper selection of a heat exchanger is crucial to ensure that collected solar energy is transferred to storage and/or the load.



OPERATION:

1. FILL FLUID RESERVOIR  
WITH SOLAR LOOP FLUID
2. OPEN VALVES TO BOOSTER PUMP
3. START BOOSTER PUMP
4. START SOLAR LOOP PUMP
5. FILL SYSTEM

FIG. 23 - FILL BOOSTER PUMP SCHEMATIC

For this manual, the following heat exchanger types and parameters should be used:

- o Shell-and-tube or plate type;
- o Counterflow, parallel-counterflow or 2-4 multipass counterflow only; and
- o Heat exchangers for swimming pools shall be constructed of cupronickel or stainless steel where wetted by poolwater.

Extra care must be taken in sizing heat exchangers for solar energy systems because, unlike most other heating systems, the level of energy to be transferred (BTUH) varies widely during normal operation. A particular sizing technique that lends itself well to this application is the NTU Method (Number of Transfer Units) since specific (fixed) inlet/outlet temperatures are not required. Basically, the NTU method eliminates the iterative calculations necessary with the log-mean-temperature-difference (LMTD) approach by using a method based on the effectiveness of the heat exchanger in transferring a given amount of heat. This method also is advantageous in comparing various types of heat exchangers to meet a specific objective.

To use the NTU method for sizing heat exchangers, the following assumptions and calculation procedures are shown:

### Assumptions

1. The hottest fluid will always be the solar loop fluid for heat exchangers between the solar loop and storage and shall always be the storage tank fluid for heat exchangers between solar storage and the load.
2. The cold fluid will be the other fluid (storage or load) relative to assumption 1.

These assumptions are based on the premise that the heat exchanger being designed will not be in operation unless the solar loop is hotter than storage or storage is hotter than the load (control logic requirement).

The next step in the NTU method is to calculate the capacity rates for both fluids in the heat exchanger. To obtain good performance from the heat exchanger, the capacity rate for the hottest fluid should be less than the capacity rate for the cold fluid to ensure that a maximum amount of energy is transferred. Therefore, the capacity rates for the two fluids are defined as

$$C_{MIN} = m c_p \text{ (hot fluid) and,}$$

$$C_{MAX} = m c_p \text{ (cold fluid)}$$

where,

$m$  = mass flow rate, lbs. per hr.

$c_p$  = specific heat, Btu/lb °F



For a heat exchanger between the collectors and storage, as in a closed loop glycol system, CMIN is easily calculated from the collector loop flowrate, previously specified, and the specific heat of the water/glycol mixture. At this point, the flowrate between the storage tank and the heat exchanger (cold fluid) has yet to be defined and can now be properly determined. CMAX should be greater than CMIN for good performance. CMAX should be designed to equal 1.25 to 2.0 times the value of CMIN, or

$$1.25 \text{ CMIN} \leq \text{CMAX} \leq 2.0 \text{ CMIN}$$

The cold fluid should never have a capacity rate less than that of the hot fluid!

For a heat exchanger located between the solar storage tank and the thermal load, the requirements are the same, but the approach is reversed. For this situation the procedure would be

1. Calculate CMAX - the load flowrate should already be known at this point. Exercise care regarding fluid specific heat for process loads because it may not be water on the load side of this exchanger.
2. Calculate CMIN - divide CMAX by a value of 1.25 to 2.0 to determine CMIN.
3. Using the specific heat of the solar storage fluid calculate the required flowrate from the storage tank to the heat exchanger (hot side).

Next, calculate the ratio of CMIN to CMAX from the values determined above.

$$\text{CMIN/CMAX} = \text{ratio}$$

The value of this ratio should fall between zero and one.

Once a ratio for  $C_{MIN}/C_{MAX}$  has been determined, the designer can begin to calculate the approximate surface area required for the heat exchanger. Again, some assumptions and/or engineering judgment are required. These are

1. The overall heat transfer coefficient for the types of heat exchangers being considered will be approximately
  - a. Water-to-water,  $U = 250 \text{ Btu/sq. ft.} \cdot ^\circ\text{F} \cdot \text{hr.}$
  - b. Water-to-water/glycol,  $U = 200 \text{ Btu/sq. ft.} \cdot ^\circ\text{F} \cdot \text{hr.}$

These represent fairly conservative  $U$  factors for heat exchangers and include a fouling or dirt factor of 0.003.

2. The designer should calculate the surface area required on the basis of the heat exchanger effectiveness,  $E$ , being in the range of 60-80%.

At this point, the following information has been calculated or determined:

$C_{MIN}$ ,  
 $C_{MAX}$ ,  
 $C_{MIN}/C_{MAX}$ ,  
 $U$  factor, and  
effectiveness,  $E$ .

Now refer to Fig. 24 through 26 for the general performance curves of the various heat exchangers. To use the curves to calculate the surface area required, use the following steps:

1. Locate the applicable CMIN/CMAX curve.
2. Select a value of E between 60 and 80%.
3. Locate the intersection of the selected effectiveness line and the CMIN/CMAX curve.
4. Follow the vertical line from this intersection down to determine the NTU.
5. Calculate the approximate surface area using the equation

$$A = C_{MIN} [(NTU)/U]$$

A more complete discussion of the NTU method can be found in Ref. 13.

The collector/storage heat exchanger is critical to the overall performance of the system. If this heat exchanger is undersized, the transfer of energy from the collectors to storage can be severely restricted. Because the heat exchanger is a minor cost item compared to other components, relatively little effort is normally spent on its design.

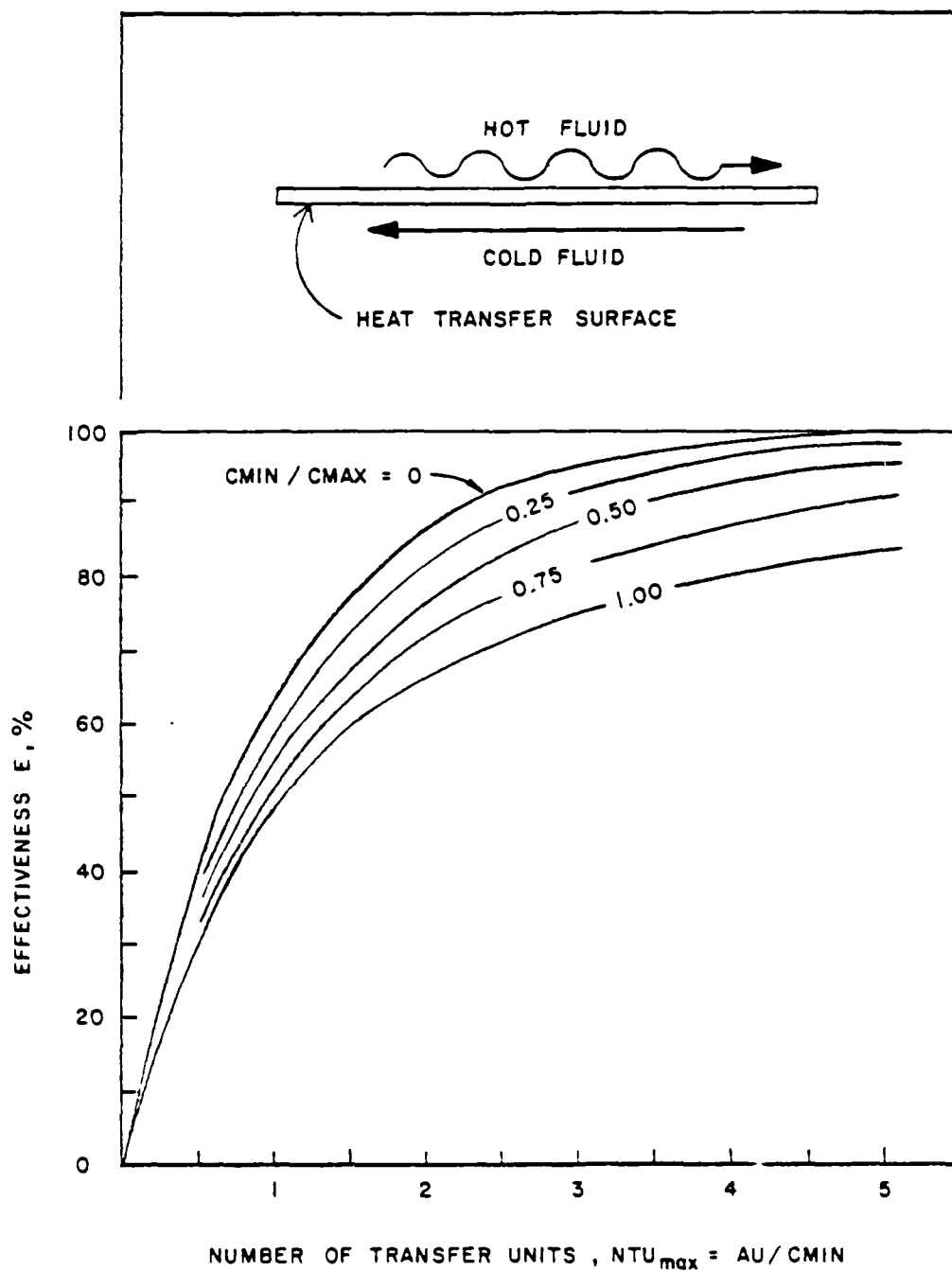


FIG. 24 - COUNTERFLOW HEAT EXCHANGER EFFECTIVENESS

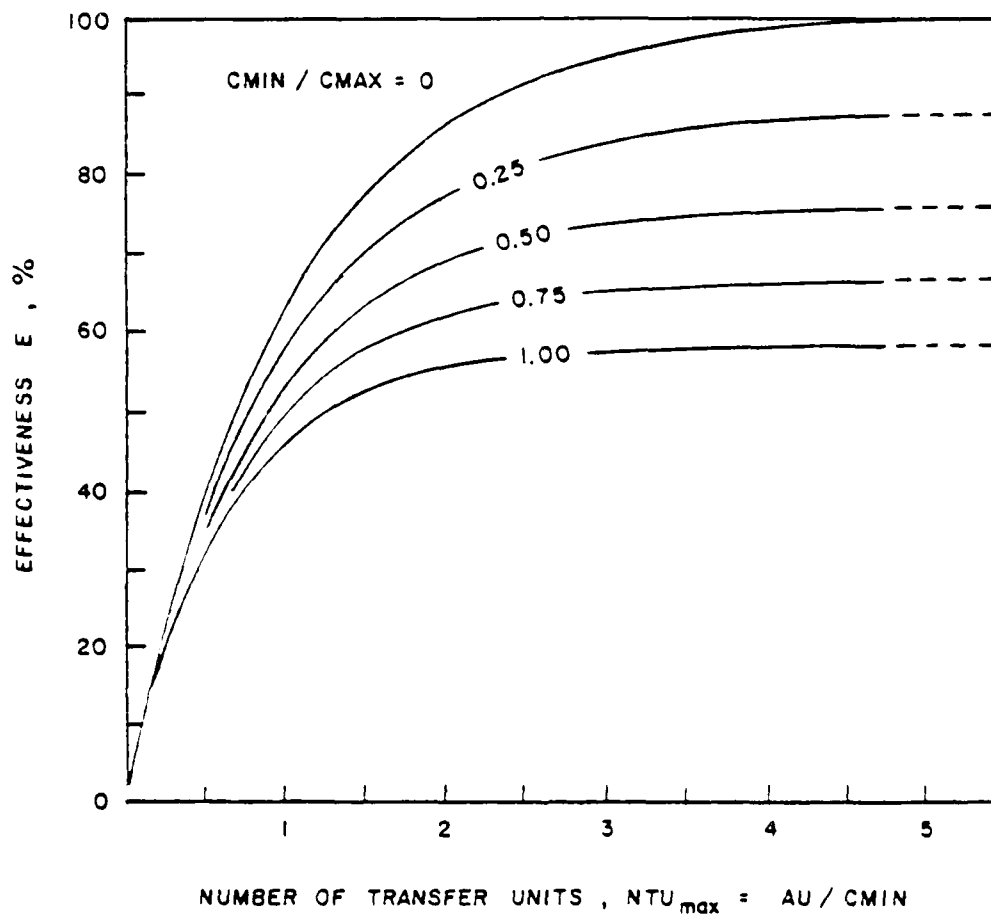
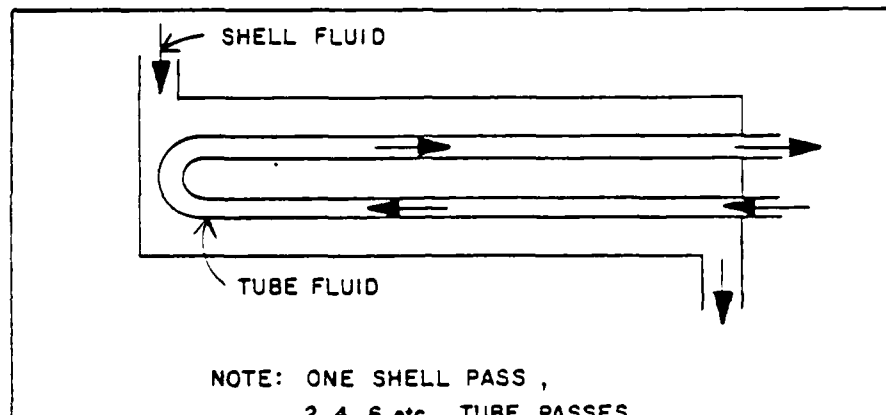


FIG. 25 - ONE - TWO PARALLEL COUNTERFLOW  
HEAT EXCHANGER EFFECTIVENESS

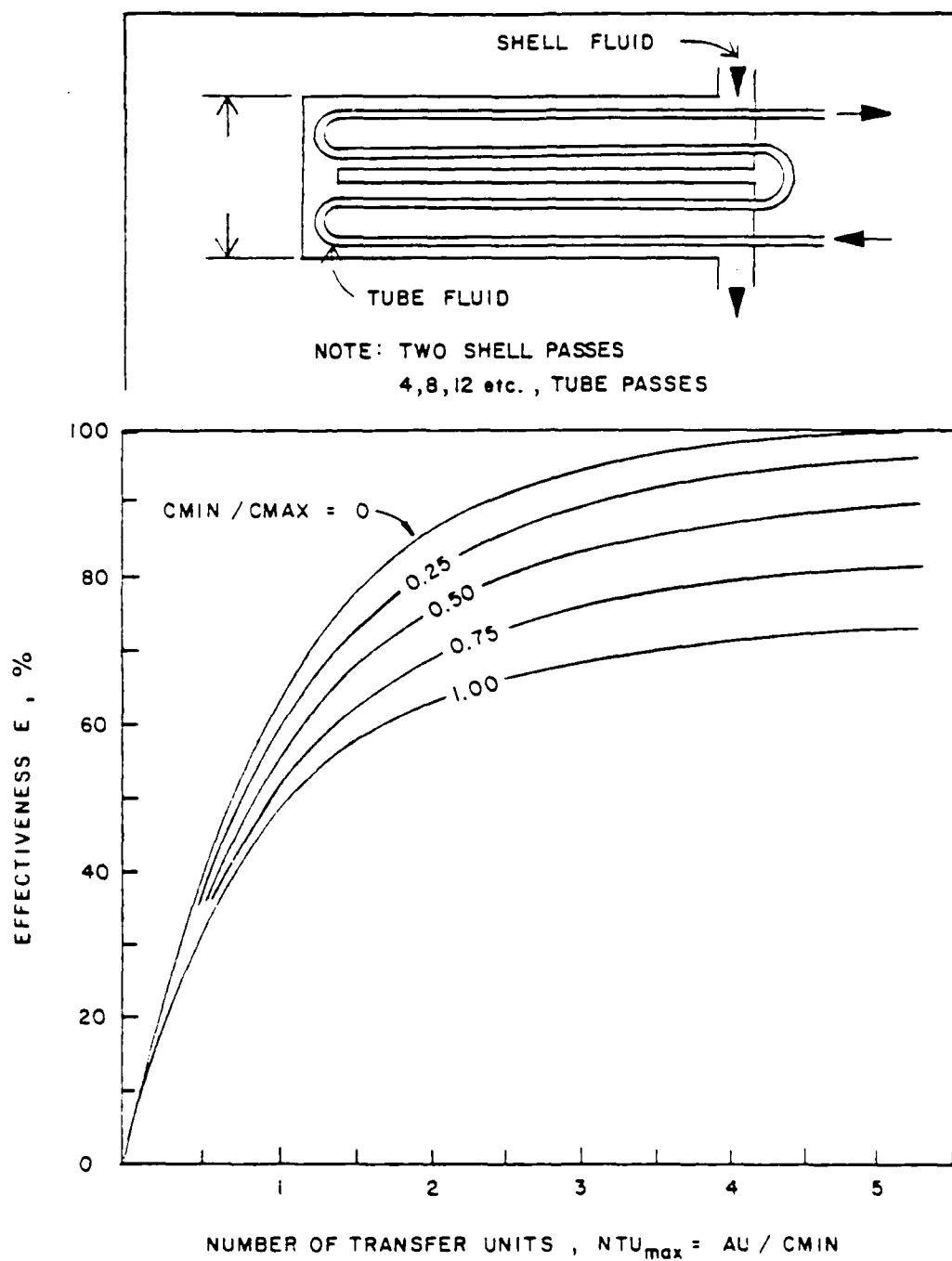


FIG. 26 - TWO-FOUR MULTIPASS COUNTERFLOW  
HEAT EXCHANGER EFFECTIVENESS

## Insulation

The true economics of the solar energy system is based upon the premise that a maximum amount of the solar energy collected is delivered to the thermal load being addressed. Collecting thermal energy with a solar system involves considerable initial expense, and, therefore, as much of that energy as possible should be retained by insulating the system. This does not mean, however, that the designer should use the thickest possible insulation, because there is a point where the additional cost of thicker insulation is higher than the value of the energy saved over the lifetime of the system. Increasing the amount of insulation on a hot surface decreases the amount of energy lost from that surface, and it reduces accordingly the amount of energy that would otherwise have to be made up by additional collector area or by an auxiliary source. The effect is inversely logarithmic, however, so each additional increment of insulation saves less energy than the one before. To this decreasing cost of lost energy, we must add the increasing cost of the insulation itself. The total cost exhibits a minimum value at some optimal insulation thickness.

Historically, solar system designers have tried to calculate the optimum insulation thickness for piping and storage tanks using life-cycle costing techniques. Although this is the preferred method, the designer does not always have reliable economic data available (i.e., long-term fuel costs) for this analysis. Therefore, because it is outside the scope of this manual to attempt to provide this data, the following design criteria are

provided as a minimum for use by the designer. The following insulation R values are recommended for use in the system design:

Piping  $\leq$  1.0 inch normal diameter,  $R \geq 4$

Piping  $>$  1.0 inch normal diameter,  $R \geq 6$

Storage tanks  $\leq$  140°F (average),  $R \geq 30$

Storage tanks  $>$  140°F (average),  $R \geq 40$

Designers who are unsure of the temperature parameter (average) for storage tanks in these solar energy systems may use the following default values in their calculations. These default values are:

DHW - 130-140°F

Space Heat - 140-150°F

Space Cool - 170-190°F

IPH - 140-150°F

Note that these are default values only, especially with IPH systems which may be applied at virtually any temperature.

For storage tanks, the designer should base calculation of required insulation on the criteria that heat loss from storage be limited to five percent in a 12 hour period. The storage capacity of the tank can be calculated by the equation

$$\text{Capacity} = Mc_p \Delta T$$

where,



$M$  = mass of stored fluid, lbs

$C_p$  = specific heat of fluid, Btu/lb  $^{\circ}\text{F}$

$DT$  = temperature differential,  $^{\circ}\text{F}$  ( $T_2 - T_1$ )

Note that the upper operating temperature of the tank should be the overtemperature setting of the control system, normally 180-195 $^{\circ}\text{F}$ . The lower temperature should be the minimum useful temperature of the tank.

A variety of insulating materials can be used to insulate both piping and storage tanks. R values for some common materials are given in Table VIII.

**TABLE VIII**  
**INSULATION R VALUES**

Material	R Value (per inch)	Max. Temp., $^{\circ}\text{F}$
Calcium Silicate	2.44	1200
Cellular Glass	2.10	800
Fiberglass, board	3.03	400
Fiberglass, pipe	3.45	350
Polystyrene, extruded	5.00	170
Polyurethane	6.25	210
Foam Rubber	4.35	150

In selecting a particular insulation for the job, the designer must be careful to ensure that the best insulation for the application is used. For example, a closed-cell foam type is better for outdoor application than fiberglass unless the fiberglass is adequately protected from becoming wet. The following general criteria can be used in selecting types of insulation:

#### Piping-Interior

- o Closed-cell foam (molded);
- o Mineral fiber (molded);
- o Calcium silicate (molded);
- o Insulate fittings, joints, and valves; and
- o Finish with glass cloth, PVC jacket, canvas, aluminum or stainless steel jacket.

#### Piping-Exterior

- o Closed-cell foam (molded), UV inhibited;
- o Mineral fiber (molded) - definite second choice to closed-cell foam;
- o Insulate all fittings, joints and valves; and
- o Finish with aluminum or stainless steel jacket with vapor barrier. Locate all seams on bottom of piping.

#### Piping-Underground

- o Closed-cell foam (molded) with vapor barrier jacket and petroleum based (asphaltic) exterior coating;
- o Inert, inorganic, nontoxic and nonflammable granular insulation in trench

### Finalize Load Interface

The solar energy system must be properly interfaced with the thermal load it is to address for a truly successful design. The interface should be designed to maximize the use of solar energy while minimizing the control requirements. The interface of the solar system and the load (or conventional heating system) is frequently neglected area of design. Often the solar system designer and the conventional mechanical system designer are not the same person, and each mistakenly assumes that the other is designing the interface. To avoid this problem, the solar system designer shall design the actual interface and coordinate with the conventional mechanical system designer.

System interface was discussed briefly in Chapter IV - Schematic Design. As shown, DHW systems can be simply addressed in either a direct preheat (Fig. 9) or a parallel, indirect system (Fig. 10). In both these cases, a three-way valve controls the interface of solar with conventional. These three-way valves should be thermostatically controlled, self-adjusting valves. Do not use electrically or pneumatically controlled solenoid valves if possible.

The designer must be extremely careful at this point to ensure that the actual hot water in the DHW supply is limited to 120-125°F to prevent scalding of users. This can easily be accomplished by mixing valves at the interface. Do not, however, limit the solar storage tank to these temperatures.

Space heating systems can be connected in a variety of ways to the load, depending on the type of mechanical system used. In interfacing the solar system with the conventional space heating system, the following criteria should be considered:

1. The solar system can address only the load defined by the temperature difference between the heating system supply and return. For example, a hot water coil has a supply temperature of 140°F and a return temperature of 120°F. Therefore, the solar system can address only this 20°F differential and solar storage temperatures below 120°F are not useful. Because of this, the interface control must bypass solar if solar storage is below the return temperature of the heating system.
2. Avoid an interface design in which the conventional back-up heater is required to maintain the solar storage tank at some threshold temperature; the solar storage tank should be heated only by the solar system.
3. The interface design must allow the solar system to address the load before the conventional heating system does. That is, in a supply/return heating loop, the solar interface should occur before the return reaches the conventional heating unit.

In a combination SH/DHW system the following criteria also apply:

1. Address the highest quality load (highest temperature) first to ensure maximum use of solar.
2. Control logic and/or piping of the interface should be such that the heating system (conventional) is not required to operate for the solar system to address the DHW load.
3. Do not allow the solar system to provide hot water exceeding 120-125°F directly to DHW fixtures. Provide thermostatic mixing at the interface to protect users from scalding. Do not, however, limit the solar storage tank to these lower temperatures.

Space cooling (SC) and SWP systems shall be interfaced as shown in the system schematics of Chapter 1. The SWP system types are defined by the type of interface used (direct or indirect), and the SC system should be such that the solar system can be disconnected from the cooling system without interrupting service.

The interface requirements for IPH are dependent on the process heat system requirements. The most important interface parameter to consider here is the process load schedule. If the process

to 5:00 pm, the solar system can be interfaced as if it were just another heating unit, and the storage tank can be eliminated completely or reduced to a buffer tank that stores only one to two hours' worth of collected energy.

### Finalize Control System

The final control system design should be done as essentially the last item in the Design Development phase to allow the designer to view the system as a whole and to avoid coordination problems generated by a changing design.

As discussed in the Schematic Design section, the control system should be as simple as possible for minimal downtime and maintenance. The following items should be finalized before the control system design is completed:

- o Basic system type (i.e. closed loop, drainback, etc.),
- o Basic equipment selection and sizing,
- o Array and equipment layout, and
- o Load interface.

The following steps are recommended in final control system design:

1. Define the control logic needed to operate the system:
  - o Differential "on" and "off" settings for the type of system selected as defined in Schematic Design.

- o Define all equipment to be controlled such as pump(s), valve(s), etc.
  - o Define the control logic for safety operations such as high-limits or recirculating freeze protection.
2. Select an off-the-shelf control unit that will accomplish the control logic defined in Item one above. The selected control unit should have the following characteristics:
- o Off-the-shelf availability - Do not allow custom control installations. Experience has shown that custom controls are the leading cause of nonoperating systems. An off-the-shelf unit at a cost of \$500-600 can also simply be replaced more economically than repairs to custom equipment.
  - o Solid-state, self-diagnostic for sensor failure with LED digital or analog gauge display - a number of commercially available solid-state control units will indicate this by means of a flashing digital display when shorted or open. As an example, one unit will display the value "32" for shorted sensors and "212" for open sensors as an intermittent flashing.
  - o Use control units with 10K ohm thermistor sensors or nickel-platinum probes.
  - o Control units and sensors should be of the

same manufacturer and be factory-calibrated.

- o The manufacturer of the selected unit shall have been engaged in the manufacture of control units for a minimum period of at least three years and shall have a trouble-shooting service accessible by phone.

3. Produce a basic control schematic - Show the basic system schematic with all equipment to be controlled and/or monitored by the control system. Show this equipment as physically wired to the control unit in a manner similar to the basic system schematics of Chapter III - System Selection. If the power requirement of pumps or valves cannot be switched directly by the control unit, define the electrical relays necessary to accomplish the switching and show this schematically.
4. As part of the final control system design, the designer must also address the logic required for the system interface, as discussed in the previous section.
5. Describe the location and installation of the control unit and sensors completely. The control unit, for example, shall be mounted in an easily accessible location in the mechanical room. The collector sensor shall be mounted between two



collectors, in the upper header (outlet), in the row closest to the mechanical room and shall not be shadowed at any time. See Chapter VI - Construction Documents for details of installation. The storage sensor shall be located directly in the storage tank in the upper quadrant. Use a temperature sensor well for pressurized tanks.

At the completion of this section, the following shall have been completed regarding the control system:

- o A well defined control logic established.
- o Layout of the controls and controlled and/or monitored equipment shown schematically.
- o Details of installation given.

A final point to be addressed here is the delegation of responsibility between the solar system contractor and the electrical contractor for the control system. Because the solar system controls are an integral part of the solar system, the following delegation of responsibility is recommended and should be clearly defined in the construction documents:

1. The solar system contractor shall
  - a. Furnish and install the control unit as specified;
  - b. Furnish and install the control sensors as specified;

- c. Furnish control wiring (controller to sensor pigtails) to electrical contractor;
  - d. Furnish any power relays required to electrical contractor;
  - e. Make final connections of control wiring to sensors and control unit; and
  - f. Perform final checkout of controls.
2. The electrical contractor shall
- a. Furnish and install all conduit required for power and/or control wiring;
  - b. Install wiring and relays provided by solar system contractor; and
  - c. Furnish and install all electrical power requirements (material and labor) for controls and/or controlled equipment, as required, including final connections.

# DESIGN DEVELOPMENT CHECKLIST

ITEM	CHECK	
	YES	NO
1. Did Scope of Work changes affect thermal loads	_____	_____
2. If so, were thermal loads recalculated	_____	_____
3. Did thermal loads change more than $\pm 10\%$	_____	_____
4. If item #3 was yes was, array size recalculated	_____	_____
5. Is solar storage tank located underground	_____	_____
6. Hose bibb and electrical receptacle on roof or near ground mounted array	_____	_____
7. Reverse-return manifolding used	_____	_____
8. If item #7 is no, did the project manager authorize, in writing, this variance	_____	_____
9. If mechanical flow control devices were used, did these conform with requirements of this manual	_____	_____
10. Does collector row layout conform with Fig. 13 or 14	_____	_____
11. 1.0 in. header - does number of collectors exceed 8	_____	_____
12. 1.25-1.5 in. header - does number of collectors exceed 10	_____	_____
13. Do piping fluid velocities exceed 5.0 fps	_____	_____
14. Is piping type "L" copper (except indirect pools)	_____	_____
15. Solder joints specified as silver or 95/5 solder	_____	_____
16. Does design include pipe thermal expansion control	_____	_____
17. Is fluid expansion addressed	_____	_____
18. Expansion tank is "bladder" type	_____	_____
19. PRV is set between pressure of fluid at stagnation and working pressure of system	_____	_____
20. Expansion tank in mechanical room is located on suction side of pump	_____	_____
21. Pressurized tank is off-the-shelf	_____	_____
22. Length-to-width ratio approximately 2:1	_____	_____
23. Pressure vessel has access manway	_____	_____
24. Pressure vessel will have ASME stamp	_____	_____
25. If a steel tank is used, is it lined with nontoxic, low soluble cement (0.25 to 0.375 in.)	_____	_____
26. Tank has a min. of two temperature sensor wells, a PRV and a level gauge	_____	_____
27. Tank piping connections shall be as shown or similar to Fig. 22	_____	_____
28. Fluid from collectors at top of tank	_____	_____
29. Fluid to collectors at bottom of tank	_____	_____
30. Is appropriate equipment valved for isolation	_____	_____
31. Are necessary throttling valves shown	_____	_____
32. Fill/drain valve shown for solar loop	_____	_____
33. Is solar loop pump centrifugal type	_____	_____

# CHECKLIST (Con't)

34. For open loop systems, can pump overcome the static head \_\_\_\_\_
35. For closed loop system, can pump overcome the initial fill static head \_\_\_\_\_
36. If Item #38 is no, is a fill/boost pump shown \_\_\_\_\_
37. Is the pump's wetted surfaces brass, bronze, or stainless steel \_\_\_\_\_
38. If a dual pump system is used can one pump provide roughly half the flow at the head required \_\_\_\_\_
39. Is a heat exchanger used between collectors and storage or between storage and the load (IF NOT, SKIP TO QUESTION 48) \_\_\_\_\_
40. Is the heat exchanger shell-and-tube or plate type \_\_\_\_\_
41. Is it a counterflow, parallel-counterflow, or multipass counterflow \_\_\_\_\_
42. For an indirect swimming pool system is the surface wetted by poolwater cupronickel or stainless steel \_\_\_\_\_
43. Is the capacity rate, as defined in this chapter, for CMIN less than that of CMAX. \_\_\_\_\_
44. Is heat exchanger effectiveness between 60 and 80% \_\_\_\_\_
45. For piping  $\leq 1.0$  in. dia. Is the insulation R value  $\geq 4$  \_\_\_\_\_
46. For piping  $> 1.0$  in. dia. Is the insulation R value  $\geq 6$  \_\_\_\_\_
47. For storage tanks  $\leq 140^{\circ}\text{F}$  is R value  $\geq 30$  \_\_\_\_\_
48. For storage tanks  $> 140^{\circ}$  is R value  $\geq 40$  \_\_\_\_\_
49. Is outside insulation protected with a metal jacket \_\_\_\_\_
50. Has the load interface been finalized \_\_\_\_\_
51. Is the DHW supply capable of a temperature greater than  $120\text{--}125^{\circ}\text{F}$  \_\_\_\_\_
52. Does the interface design allow solar to address the load before conventional \_\_\_\_\_
53. Are SC and SWP interfaces as shown in the Chapter 1 system schematics \_\_\_\_\_
54. Has control logic been finalized \_\_\_\_\_
55. Is logic based upon temperature differential \_\_\_\_\_
56. Is control logic described in detail \_\_\_\_\_
57. Has a control schematic been prepared \_\_\_\_\_
58. Is the control unit a solid-state, off-the-shelf unit \_\_\_\_\_
59. Does it have sensor self-diagnostics \_\_\_\_\_
60. Does it have digital or analog display \_\_\_\_\_
61. Are sensors of the 10K ohm thermistor type or nickel-platinum probes \_\_\_\_\_
62. All responsibility between the solar system contractor and the electrical contractor has been clearly defined \_\_\_\_\_

\_\_\_\_\_ Initials

## CHAPTER VI

### CONSTRUCTION DOCUMENTS

#### General

Completion of the Design Development phase and approval by project management allows the designer to proceed to the Construction Documents phase. Completion of the Construction Documents phase results in essentially 100 percent completion pending final approval by project management.

The Construction Documents phase consists of finalizing the design with emphasis on installation details including the following:

- Finalize equipment selection;
- Pump installation detail;
- Heat exchanger installation detail;
- Expansion tank installation detail;
- Storage tank detail;
- Valve detail;
- Piping support detail; and
- Sensor installation detail.

At this point in the project, the actual design should be essentially complete with regard to sizing of equipment, piping and valving layout, array layout, and mechanical equipment layout. Major changes in the scope of the project should not take place at this point. The designer must now finalize all of these as-

pects and complete the design documents including drawings and specifications. Equipment installation details and final equipment selection will represent the major effort in completing the drawings and specifications.

### Final Equipment Selection

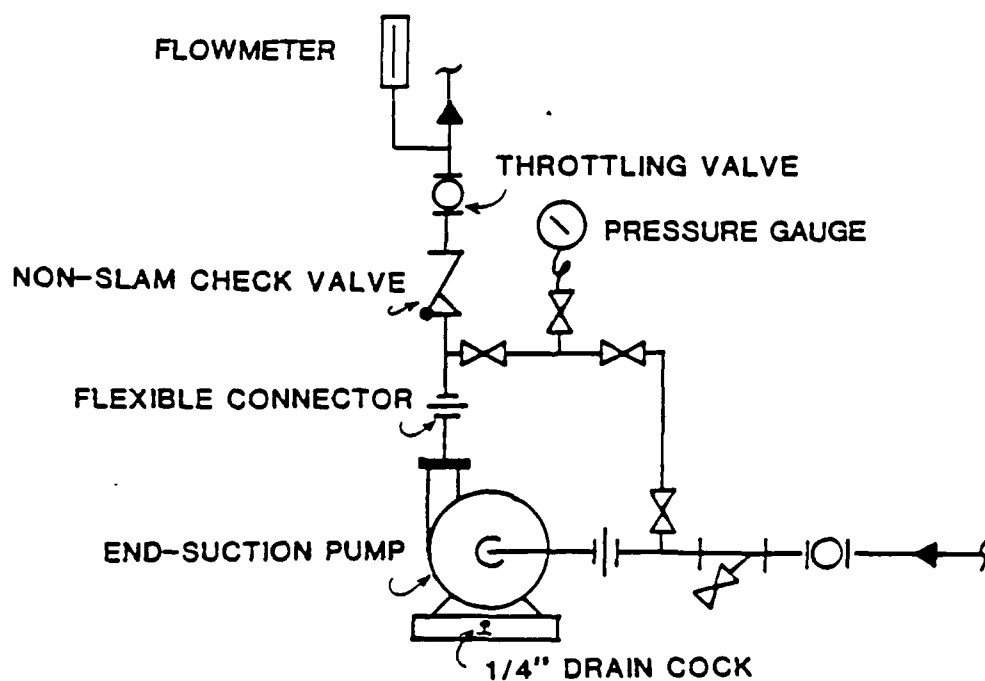
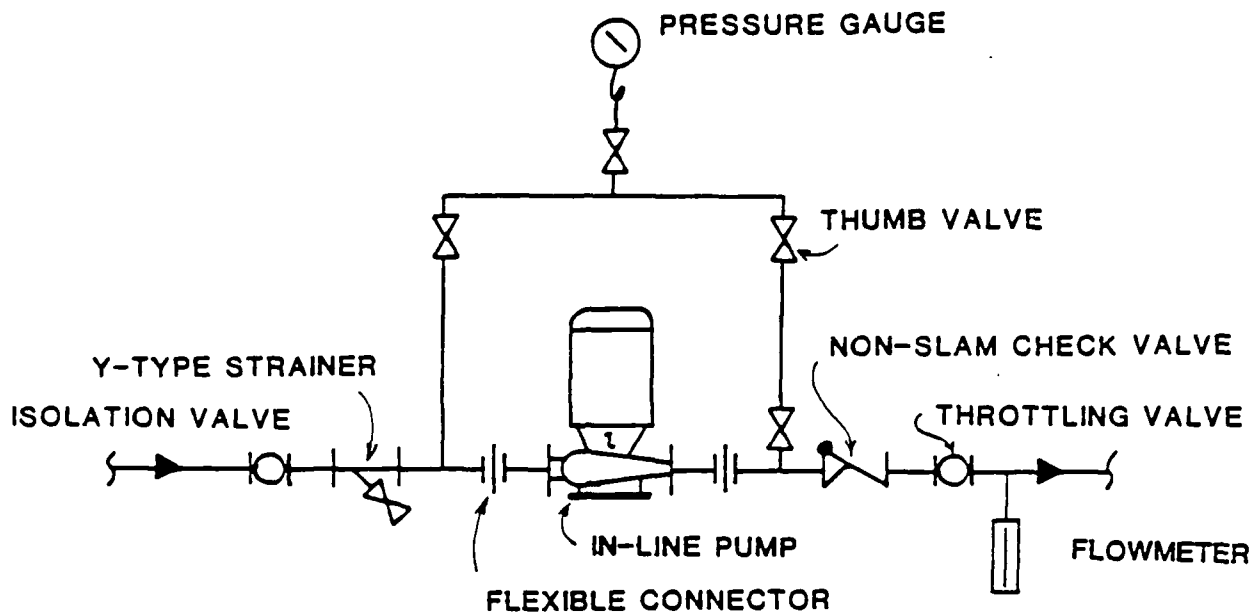
The designer should make final equipment selection for the major components of the system at this point if selection has not already been done. Although government procurement procedures do not allow the specific selection of equipment (by manufacturer), the designer must base the final design on specific units to have a comprehensive set of construction documents. Equipment selected can be named as the basis of design with the stipulation that acceptable alternates will be allowed by meeting all specifications.

### Pump Detail

The solar loop pump, as well as other pumps associated with the solar system, should be shown in both plan view and mechanical room detail. A separate installation detail should be shown for these pumps indicating required valving and other appurtenances including

- o Valves;
- o Strainers;
- o Drain/fill connections;
- o Instruments; and,
- o Special notes.

Fig. 27 shows a simple installation detail for a centrifugal pump. All items required above are shown, including special notes.



NOTE: CHECK VALVE NOT REQUIRED IN DRAINBACK SOLAR LOOP

FIG. 27 - PUMP INSTALLATION DETAIL

### Heat Exchanger Installation Detail

A detail for installation of heat exchangers should be shown to clarify the position of piping, valves, and instruments relative to the unit. A number of heat exchangers examined in the field were found to be improperly installed regarding these items.

Fig. 28 shows a basic heat exchanger installation detail.

### Expansion Tank Installation

Improperly installed expansion tanks can cause numerous problems, such as pump cavitation, for the solar system. These problems are extremely hard to diagnose for maintenance personnel and are normally not found until damage occurs. Fig. 29 shows a typical expansion tank detail that can be used. Note that the location of the expansion tank with respect to the pump and any heating unit is crucial. Expansion tanks installed on the discharge side of the pump can cause cavitation.

### Storage Tank Detail

Storage tanks are to be specified as "off-the-shelf" equipment wherever possible. Therefore, installation details are subject to the particular tank selected, but selection of the tank should be influenced by what is desired in actual installation.

Fig. 30 represents details for both vertical and horizontal tank installation. Note that the suction side of the pump should be fed from as low a point as possible to avoid creating a negative suction head; trying to pull water up to a pump at high temperatures can cause vaporization in the suction line. Also shown in



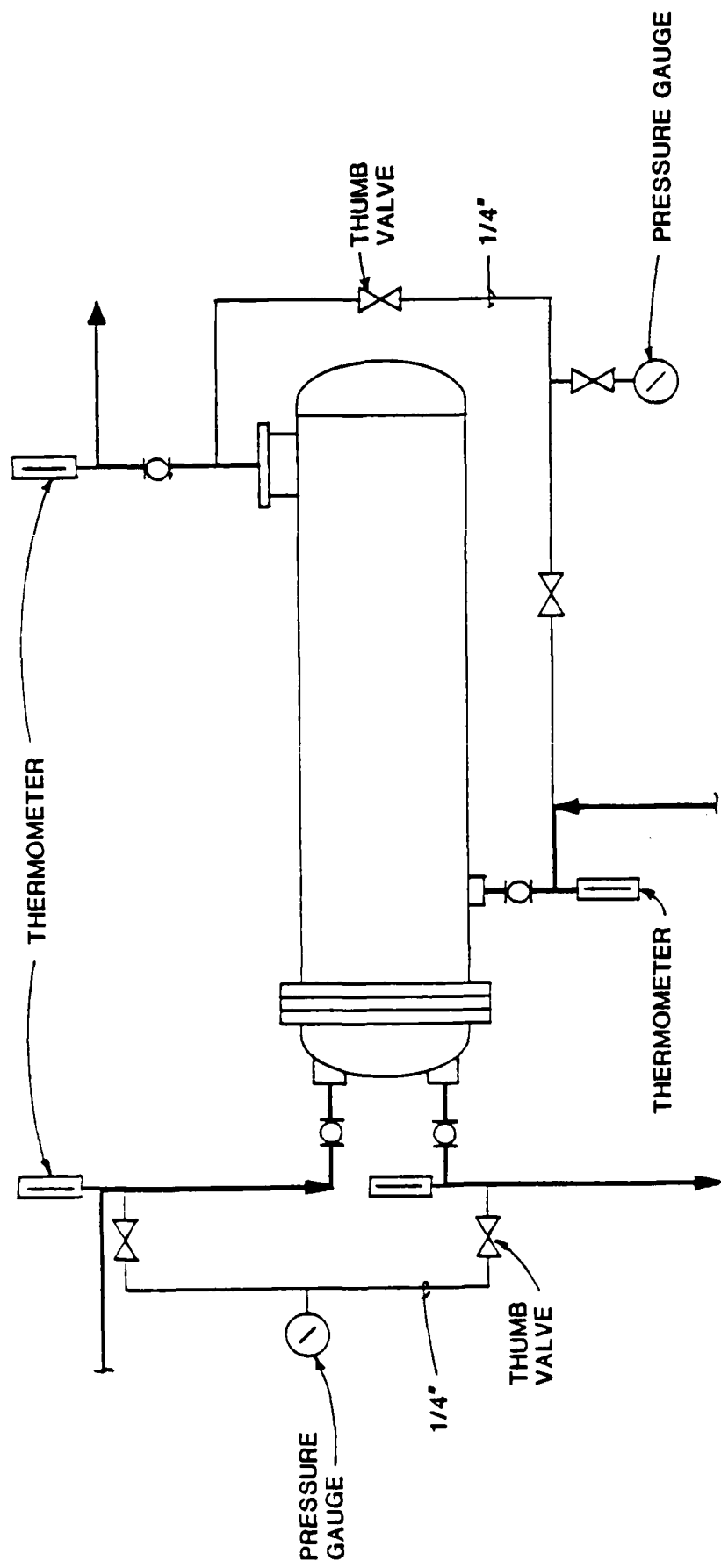


FIG. 28 - HEAT EXCHANGER INSTALLATION DETAIL

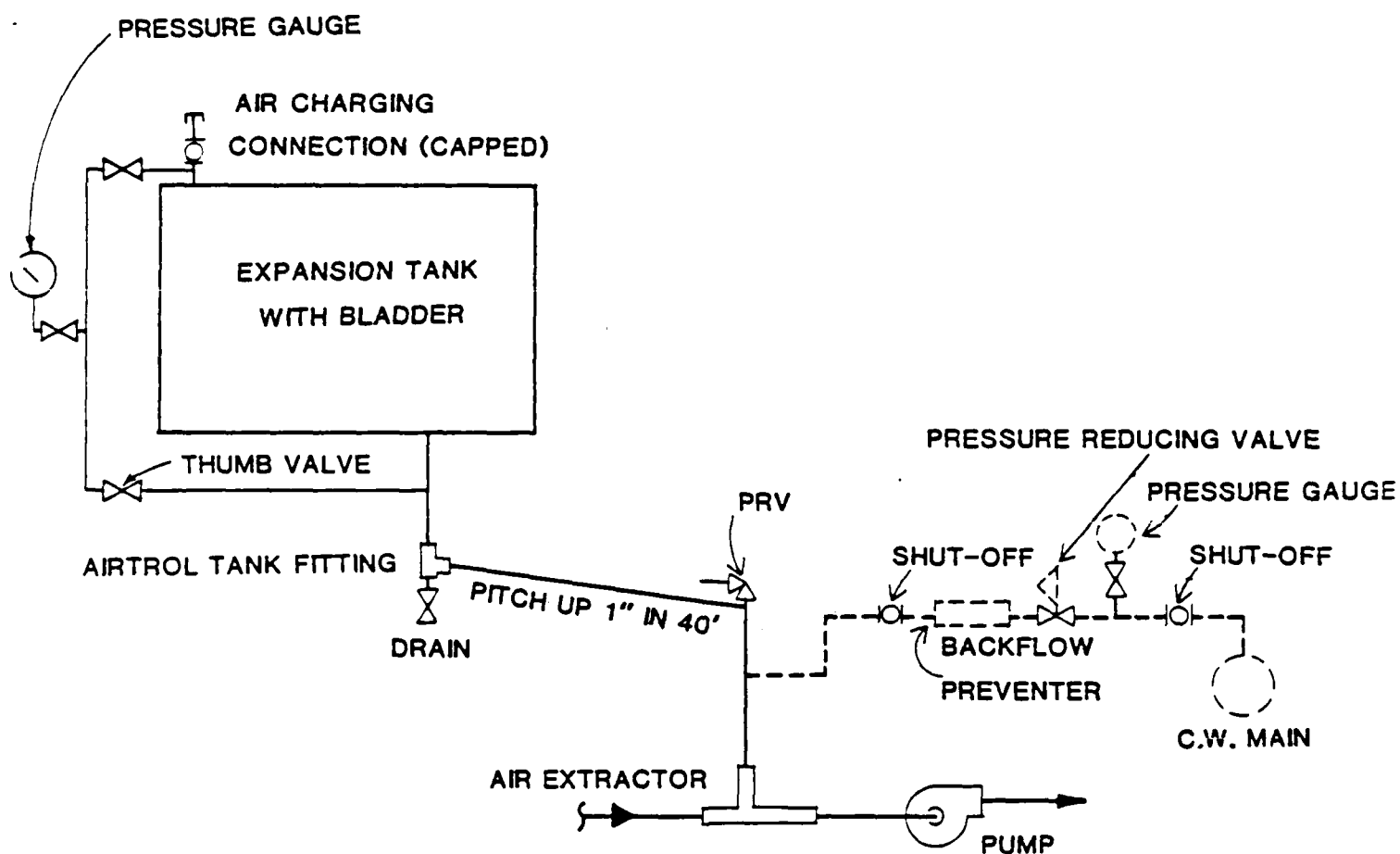


FIG. 29 - EXPANSION TANK INSTALLATION DETAIL

Fig. 30 are "thermal breaks" in all fluid lines to/from the storage tank. These constructions, which closely resemble an expansion loop, provide a thermal barrier against thermosyphon losses from the storage tank. Research has shown that this type of loss is significant.

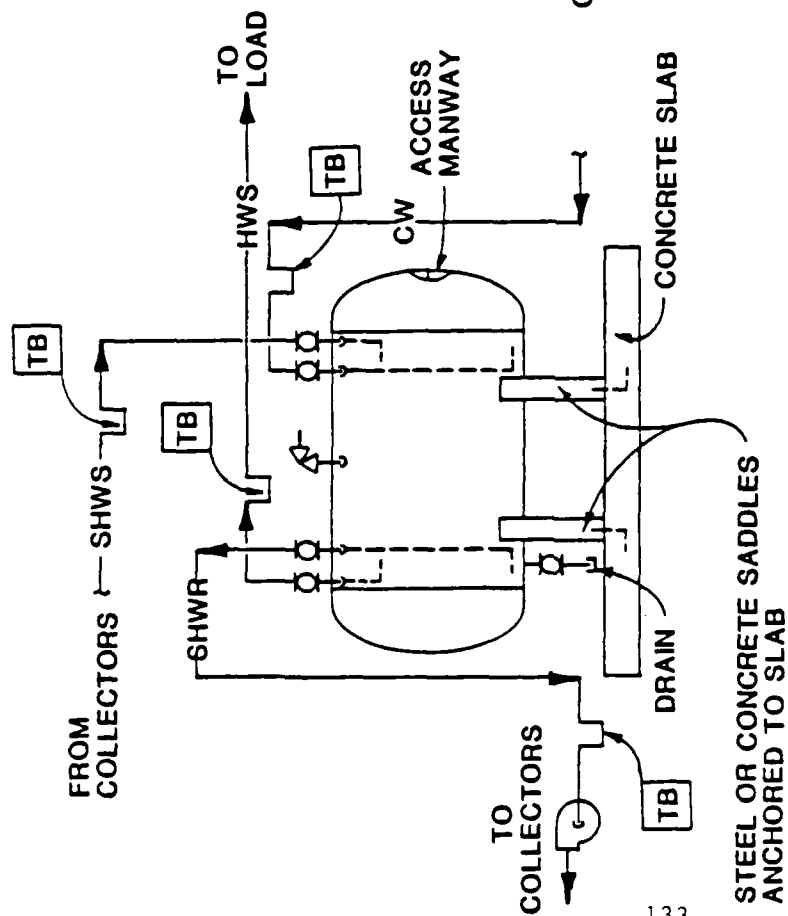
### Valve Detail

Most valves installed in existing plumbing or mechanical systems, solar or conventional, are normally installed with the stems pointing straight up. This is standard practice in the industry and in most cases it allows easier access.

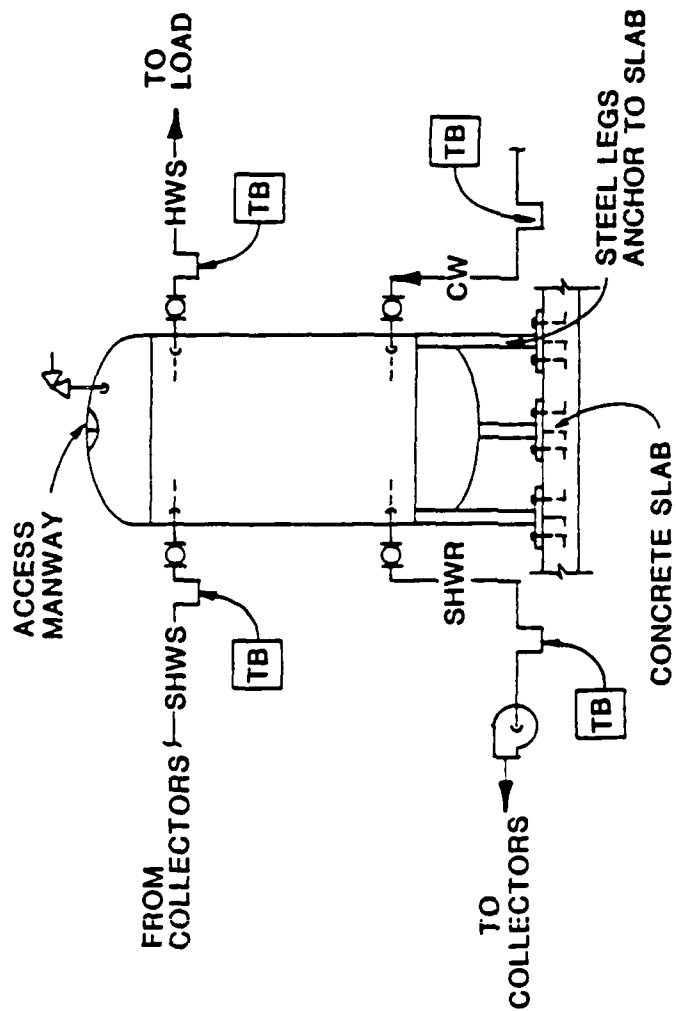
Fig. 31 shows a valve installation detail in which valves are installed with the stems a minimum of 15 degrees below the horizontal plane of the pipe centerline. The reasons for this are as follows:

- o Leaks at valve stems (common problem)  
are easily spotted by O & M workforce personnel because fluid drips off the valve stem instead of seeping into pipe insulation.
- o Insulation is not damaged by leaking valves.
- o In outdoor applications, sealing pipe jackets around vertical stems is virtually impossible.

This detail is required for all outdoor installations on horizontal (or near horizontal) piping. It is recommended but not strictly required for interior piping runs and can be



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SLAB DESIGN MUST BE SUCH AS TO PREVENT  
OVERTURNING. CHECK MOMENT.

TB - THERMAL BREAK

## HORIZONTAL TANK

## VERTICAL TANK

FIG. 30 - STORAGE TANK INSTALLATION DETAIL

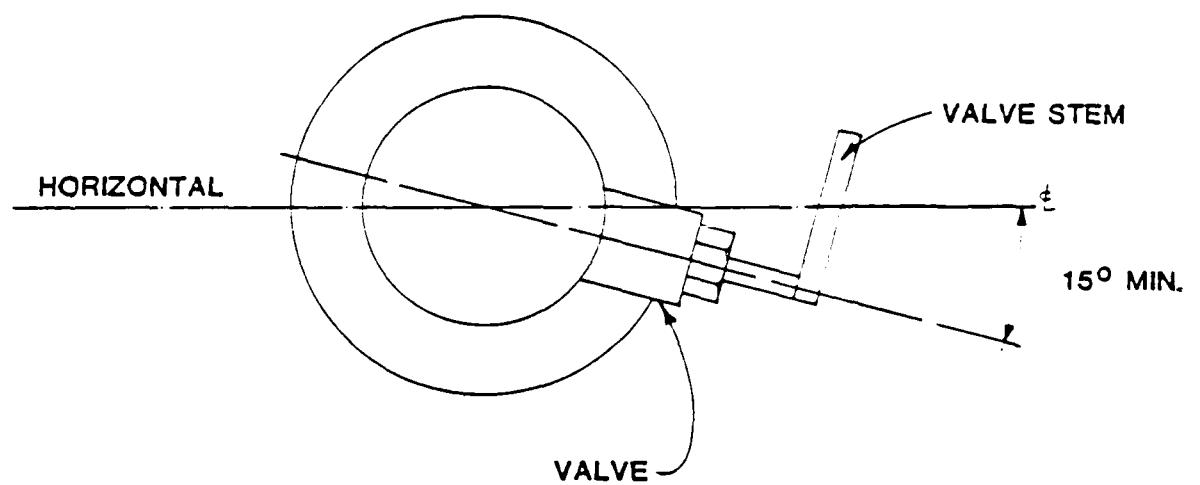


FIG. 31 - VALVE INSTALLATION DETAIL

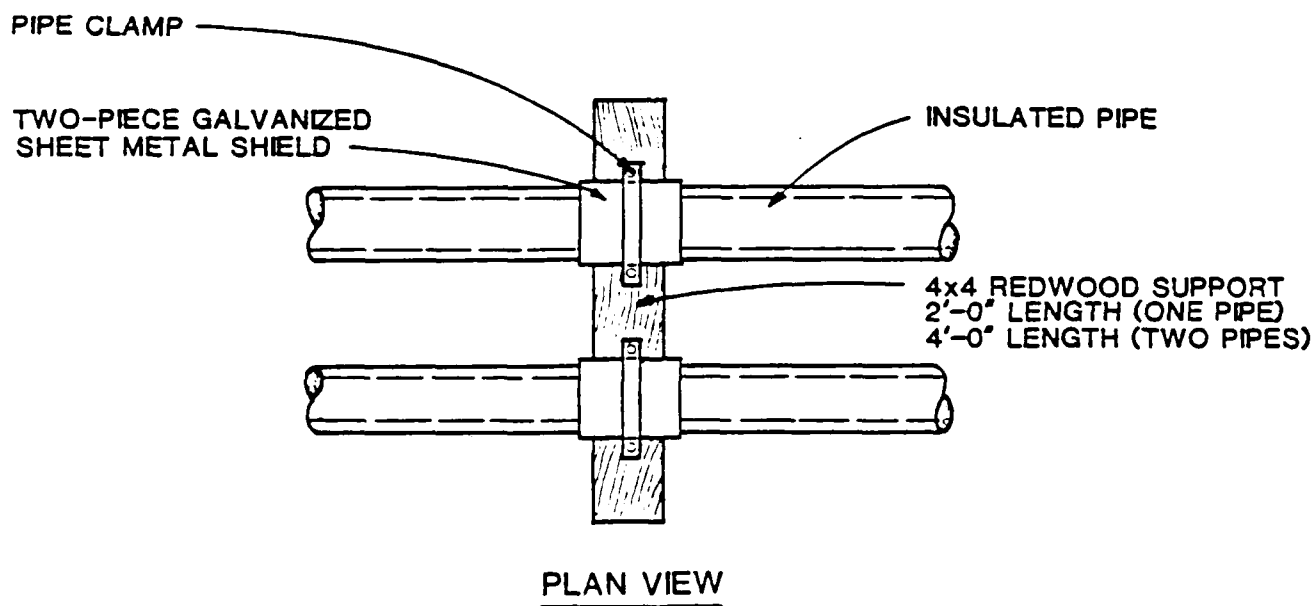
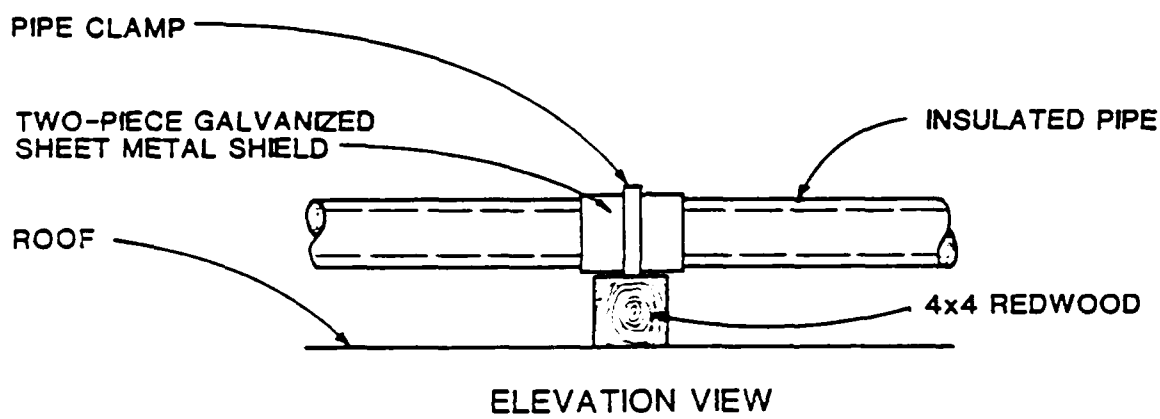
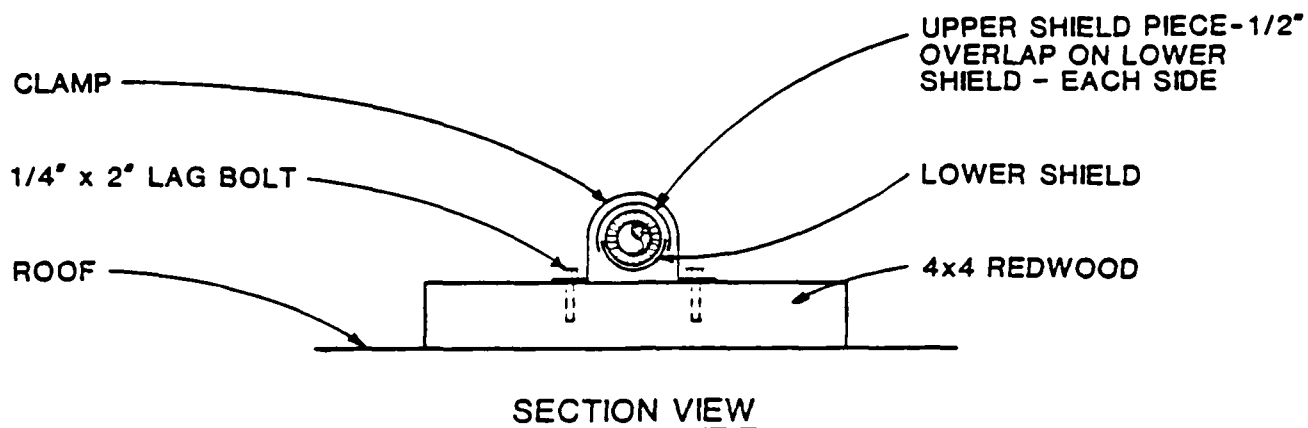


FIG. 32 - ROOF PIPE SUPPORT DETAILS

disregarded where accessibility is concerned. Obviously, it is not required on vertical piping.

### Piping Supports

Piping runs must be supported sufficiently to avoid sagging and possible damage. Minimum spacing for supports were discussed previously and are also requirements of various applicable building codes. Piping can be supported by a wide variety of hangers, clamps, brackets, and trays, all of which are available commercially in a variety of shapes, sizes, and methods of attachment.

Fig. 32 shows a simple and inexpensive method of supporting roof piping using redwood runners. This detail is provided to show an easy method for supporting pipes (not anchoring) on flat, built-up roofs where penetrations should be kept to an absolute minimum. Additional piping support details are shown in Appendix D.

### Control Sensors

One area found to be a continual source of problems for existing solar systems inspected in the field was the location and/or installation of control sensors. Fig. 33 shows a detail for installation of a 10 K ohm thermistor sensor as a collector sensor. As shown, the sensor is installed in the fluid line (not a strap-on), between two collectors in the top (outlet) header to ensure that collector fluid is being sensed and is especially

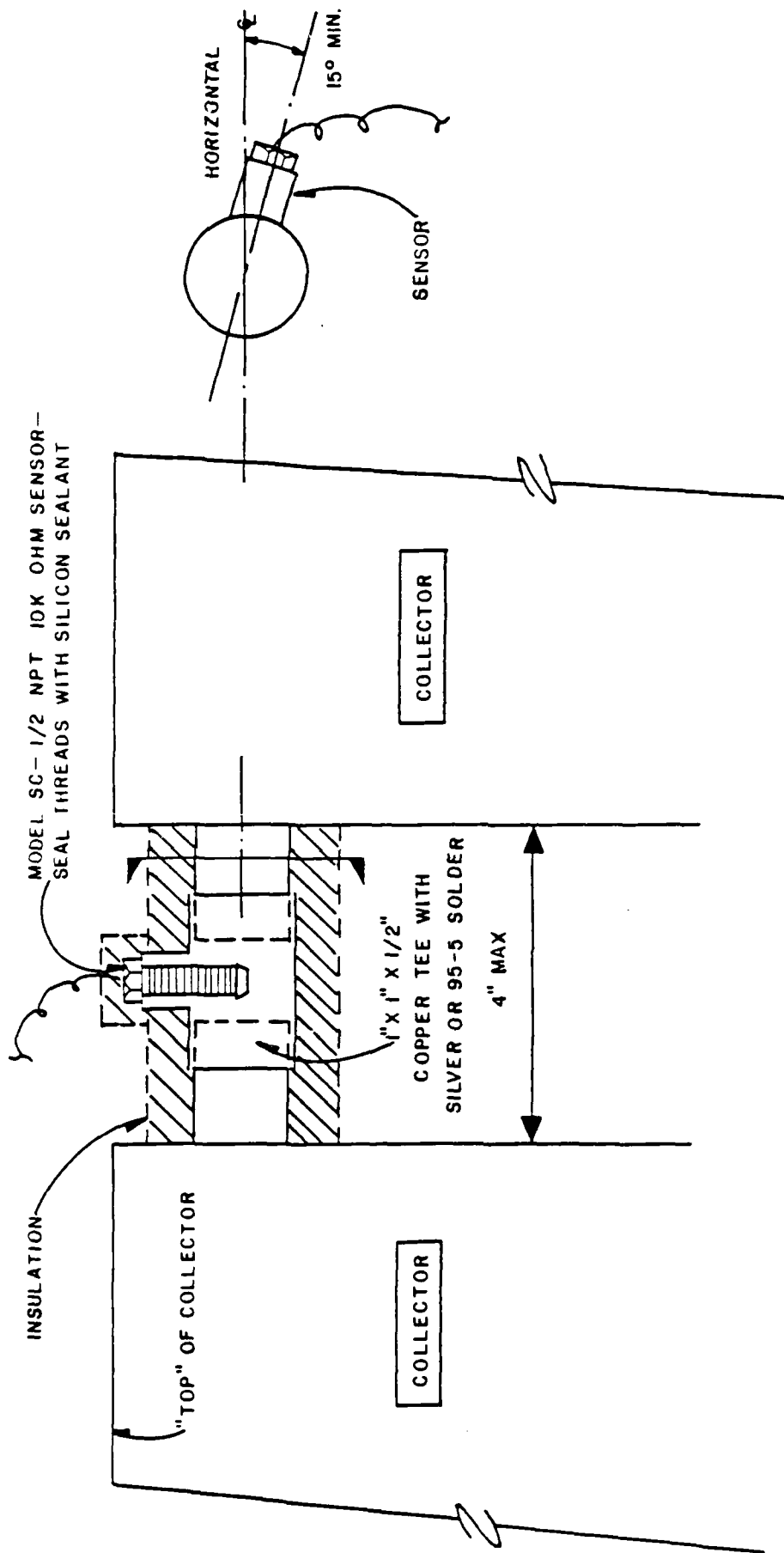
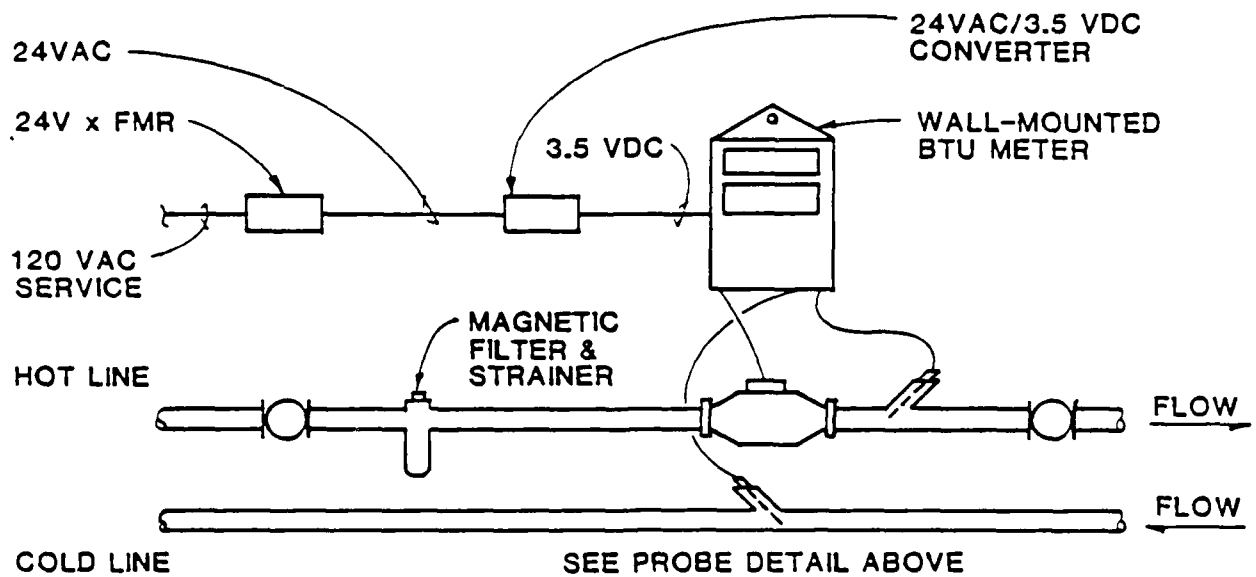
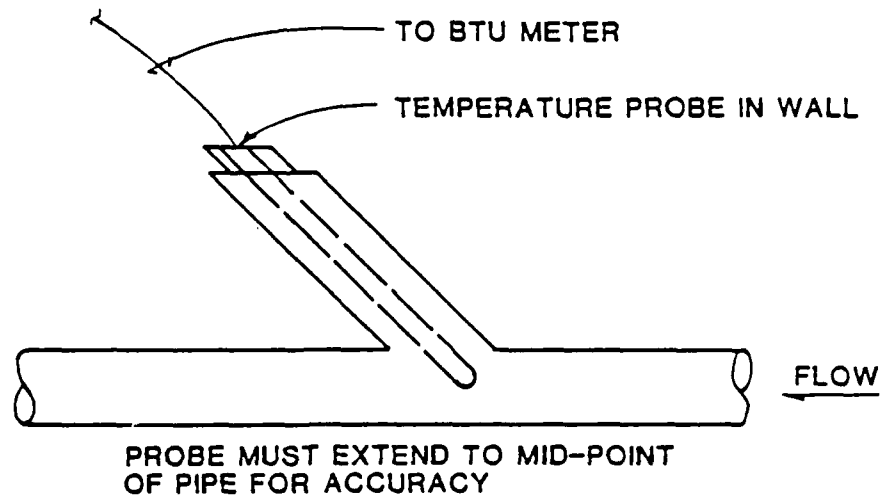


FIG. 33 - COLLECTOR SENSOR INSTALLATION DETAIL





**FIG. 34 - BTU METER INSTALLATION DETAIL**

critical for start-up. Do not install collector sensors more than 2 inches from a collector outlet. Tank sensors should be installed in the tank, in wells, if possible. Avoid installing sensors in supply or return lines to the tank.

### Specifications

As part of the construction documents package, the written specifications for the solar energy system shall also be completed and submitted for review. Normally, solar energy system specifications will be a subsection of Division 15 - Mechanical. While actual, detailed specification of solar energy system equipment is not within the scope of this manual, a number of general criteria should be followed in preparing these specifications. This is especially important if the solar energy system designer and the conventional mechanical system designer are not the same person. These are:

1. Ensure that the general mechanical conditions  
do not conflict with piping type or solder type  
requirements of the solar system.
2. Ensure that pump specifications, if different,  
are separately defined for the solar system.
3. Ensure that insulation specifications, if different,  
are separately defined for the solar system.
4. Ensure that submittals are required for all  
pertinent equipment in the solar system. As a  
minimum, submittals shall be required for the  
following:
  - o Collectors and collector supports (shop

drawings);

- o Pumps;
- o Heat exchangers;
- o Expansion tanks;
- o Storage tanks;
- o Drainback tanks
- o Controls;
- o Valves; and,
- o Instruments.

5. Ensure that the responsibilities of the solar system contractor, other mechanical contractors, and the electrical contractor are clearly defined.
6. Ensure that specifications require the flushing and pressure testing of the solar system piping.
7. Define responsibility for coordination of the contractor's work.
8. Operational test, O&M manual, and spare parts, as defined in Chapters IX and X, are required.

### CONSTRUCTION DOCUMENTS CHECKLIST

ITEM	CHECK	
	YES	NO
1. Equipment selection has been finalized	_____	_____
2. Pump installation is detailed	_____	_____
3. Heat exchanger installation is detailed	_____	_____
4. Expansion tank installation is detailed	_____	_____
5. Storage and/or drainback tank detail shown	_____	_____
6. Valve and piping supports detailed	_____	_____
7. Sensor installation detail shown	_____	_____
8. Specifications are complete and acceptable	_____	_____
9. Submittals are required for all solar energy system equipment as specified	_____	_____
10. Operational test, O&M Manual, and spare part requirements are detailed in specifications	_____	_____

\_\_\_\_\_ Initials

## CHAPTER VII

### INSTRUMENTATION

#### GENERAL

This chapter addresses only the basic instrumentation that should be included in the system design. The purpose of this instrumentation is to allow maintenance personnel to ascertain the operation of the system, not to determine the performance. This instrumentation should be installed regardless of any data acquisition system used.

1. System differential control unit - The solar system control unit, as specified in Chapter V - Design Development, will be one of the most useful pieces of instrumentation for maintenance personnel. As required, the control unit should be a solid-state, digital or analog display unit that is self-diagnostic for sensor failure. As a diagnostic tool for maintenance personnel, this type of unit has extreme value. From the control unit location in the mechanical room, maintenance personnel can check both collector and storage temperatures to determine if differentials are working. Storage tank upper limit settings can be checked, as well as heat loss from the tank (over time). Auxiliary sensors can be used for other diagnostic functions as well.

2. Solar loop pump - a means of determining the solar loop flowrate is required. The first choice is to use a visual flowmeter installed in the outlet side of the pump downstream of the throttling valve. Second choice would be to use a differential pressure meter (i.e., circuit setter type). This type of flow measuring device requires a separate portable meter be used and in this case, the meter should be kept onsite in the mechanical room. Final choice would be the use of pressure gauges on the suction and discharge sides of the pump. Differential pressure can be used with the published pump curve to roughly establish flowrate. Note that a pressure gauge is required for the pumps in any case. It is best to use a single gauge with valved connections to both the suction and discharge sides as shown in the Construction Documents chapter. If a heat exchanger is used between the solar loop and the storage tank, the pump circulating fluid between the tank and the heat exchanger should also be instrumented in a similar manner.
  
3. Heat Exchanger - Temperature differentials across heat exchangers must be known to determine proper operation of the exchanger. Also, if untreated water is used on either side of the unit, pressure gauges should be used to monitor changes in differential pressures that indicate scaling in the unit. (See

Figure 28 shown previously). Visual indicating, mercury thermometers, installed in wells shall be used.

4. Collector Rows - A thermometer (mercury type), installed in a well, should be used at the outlet of each row. Thermometers can be used at this location to determine if balanced flow conditions exist because the output temperatures for the rows should essentially be the same. Thermometers can also indicate possible problems, such as blockage of lines, within collector rows.
5. Storage Tanks - Temperature indicating devices are also required for storage tanks. For pressure vessels, thermometers in wells installed in the tank walls are required. A minimum of two, one at the top and one at the bottom, is recommended. Pressure vessels shall also have a pressure gauge at the top of the tank. Storage tanks shall have a visual sight level gauge that covers at least one-half of the level of the tank.
6. Mixed water temperature - The downstream side (mixed) of all three-way mixing valves should be instrumented for maintenance personnel to determine if the valve is operating properly. Many commercially available mixing valves have, as an option, a visual temperature gauge that indicates the mixed water temperature (uses control sensor of

valve). If the valve selected does not have this option available, a mercury thermometer, installed in a well, shall be required.

#### BTU Meters (optional)

Figure 34 shows the installation of a commercially available BTU meter. This is presented, not as a requirement of this manual, but for informational purposes for projects where BTU meters are required for one reason or another. The designer, in selecting a BTU meter, must be careful to avoid units where accuracy is poor at low differential temperatures. Some units have  $\pm 30\%$  accuracy at differential temperatures less than  $20^{\circ}\text{F}$ .



### INSTRUMENTATION CHECKLIST

ITEM	CHECK	
	YES	NO
1. A solid-state, digital or analog display controller is used	_____	_____
2. Controller is self-diagnostic for sensor failure	_____	_____
3. Solar loop pump has a flow measuring device, as specified	_____	_____
4. Heat exchanger loop pump has a flow measuring device	_____	_____
5. Heat exchanger is instrumented	_____	_____
6. Collector rows are instrumented	_____	_____
7. Storage tanks are instrumented for temperature, pressure and fluid level	_____	_____
8. Mixed water temperature (valves) is instrumented	_____	_____

\_\_\_\_\_ Initials

## CHAPTER VIII

### SUBMITTAL REVIEW/CONSTRUCTION OBSERVATION

#### General

Experience gained in evaluating existing systems in the field has shown certain deficiencies in the submittal review and construction observation process as it currently exists. In most cases, the person performing submittal reviews and construction observation is not the system designer as is the case in the majority of private sector projects. Therefore, the reviewer/inspector is lacking in the inherent knowledge of the designer relative to what is "right" for the system. This handicap can be reduced significantly by efforts on the part of both the designer and the reviewer/inspector for the project. It is the responsibility of the designer to prepare a set of specifications that are clear and concise and to define the type of submittals required for solar equipment. Preparation of detailed equipment specifications is not within the scope of this manual and the reader shall refer to the Solar Equipment Guide Specification Manual.

Within the project specifications, the designer shall define the requirements for the equipment submittals. As shown in the Solar Equipment Guide Specification Manual, it is suggested that a schedule of letter designations be used to define these requirements. Shown below is an example of this designation, and each piece of equipment should be identified with the

appropriate letter or letters.

The letter designated within brackets, [], is the data required.

1. [C] Catalog Data
2. [L] Equipment and Material List
3. [M] Maintenance Instructions
4. [O] Operating Instructions
5. [P] Performance Curves
6. [Q] Quality Control Tests
7. [S] Shop Drawings
8. [W] Wiring Diagrams
9. [N] Computations
10. [X] Samples

It is recommended that the contractor be required to submit six (6) copies of data specified within thirty-five (35) calendar days of contract execution (notice to proceed). The contractor should submit only one time for each item of equipment.

The reviewer/inspector should review the project specifications and prepare a list of specific equipment requiring submittals and the type of data required. Each piece of equipment is then checked off as submittals arrive. Submittals that are incomplete should be returned to the contractor for resubmission. Do not accept incomplete submittals or phone-in data.

The reviewer/Inspector shall carefully review each submittal relative to the intended function. Ensure that all options and/or accessories specified are included. Do not accept a statement that these will be provided if it is not clearly defined in the submittal data. Do not hesitate to require resubmittal and do not allow unrealistically short review periods!

Construction observation is necessary to ensure adherence to the intent of the contract documents. Again, good construction observation practice begins with the designer and ends with the Inspector. The designer should define specific observation points as a minimum, with responsibility for notification being the contractor's.

Request for construction observations shall be made by the CONTRACTOR to the CONTRACTING OFFICER for work installed under these specifications. Periodic observations shall be conducted as follows: (48 hours notice is required).

1. Roughing-in of work prior to concealment.
2. Lay-out of equipment prior to final connections.
3. Preliminary operation of equipment.
4. Prior to final acceptance.

The reviewer/Inspector should make more frequent visits if required, to ensure adherence to the contract. For each construction observation, the Inspector should prepare a written list of deficiencies (punch list) to be given to the contractor.

The Inspector should ensure that no deficiency in the work is concealed before correction of the problem has been confirmed. The designer should so state this in the project specifications.

As part of the project specifications, and as a requirement for final acceptance the contractor shall be required to maintain record drawings during the course of construction and to prepare "as-built" drawings at completion. Suggested requirements are given below:

1. Blue line prints shall be obtained from the CONTRACTING OFFICER at cost and an as-built daily record shall be maintained for pipe and equipment locations by noting all changes from the original drawings and specifications on these prints. These drawings shall also serve as work progress sheets and daily notations shall be made to show the extent of the work installed. The prints shall be kept on the site and be available for review at all times.
2. On completion of the work, one set of transparencies shall be obtained from the CONTRACTING OFFICER at cost, and all changes as noted on the record set shall be drawn in. The set of transparencies with one set of prints, shall be delivered to the CONTRACTING OFFICER prior to final acceptance.

## CHAPTER IX

### SYSTEM ACCEPTANCE

#### General

Acceptance of the system is a major milestone in the overall project. Acceptance is a statement that the finished product meets all of the requirements of the owner and in its present condition is acceptable "as is."

A solar energy system, because of the nature of its energy source and the environment that affects its performance (weather, load, time of day or year), cannot be subjected to a one-time performance test as a means of acceptance. The contractor that installs the system cannot be held responsible for the design of the system anymore than the designer can be responsible for the quality of the installation by the contractor. Therefore, a performance acceptance test in which the system must produce a certain amount of energy under given circumstances is a no-win situation because no particular entity can be held completely accountable (sole responsibility).

System acceptance is an on-going part of the overall project that must begin at the inception of the project; the first phase of acceptance begins with the solar feasibility study and ends when the operating system is turned over to the O & M workforce.

### Acceptance Method

Because system acceptance is an on-going task that covers all phases of the project including planning, design, construction and inspection, it must be the ultimate responsibility of the project manager. Each phase of the project must be evaluated and accepted in turn to result in a reliable system.

The following items should be considered integral parts of the system acceptance:

1. Feasibility study - The project manager shall review the feasibility study input and results to ensure that reliable data and sound assumptions have been employed.
2. Design
  - a. System selection - The project manager shall review the designer's selection of system type and agree to the specific system type selected. The project manager shall accept or reject the system selection.
  - b. Schematic design - The project manager shall review the schematic design report and ascertain that all required information is provided by the designer. The project manager shall determine that this design manual has been followed in preparing the design. The project manager shall accept or reject the schematic design.
  - c. Design development - The project manager shall review the design development documents for required content and adherence to the design methods

set forth in this manual. The project manager shall accept or reject the design development phase.

- d. Construction documents - The project manager shall review the construction documents for completeness and adherence to the requirements of this design manual. Although instrumentation is discussed in a separate chapter of this manual from construction documents, the design of the system at this point should reflect the use of the requirements of Chapter VII - Instrumentation. Therefore, the project manager shall ensure that these requirements are included in the construction documents. The project manager shall accept or reject the construction documents phase.

At this point in the project, the design portion of the project has been accepted; the project manager has accepted the design as complete and in accordance with requirements set forth in this manual. This is not a blanket statement by the project manager that no errors or omissions exist; it is an acceptance of the basic design and ensures that the design criteria have been adhered to. The project manager should make use of the checklists at the end of the various design chapters to ensure himself that all requirements have been met.



3. Submittal review - The project manager, either directly or through delegation of work (project engineer), shall determine that all equipment submittals for the project that are approved for use meet the requirements of the construction documents. Acceptance of inadequate equipment will negate the efforts put forth to ensure a good design. Chapter VIII contains a discussion of submittal review. The O&M manual shall be considered as a submittal as well and should be so specified. An accepted O&M manual is required as part of Final Acceptance (see Item #7 of this section).
4. Construction Observations - The project manager, either directly or through a designated representative (Inspector), shall ensure that the construction of the project adheres strictly to the requirements of the construction documents and that all installed equipment is the same equipment approved previously by submittals. Construction observation of the project is a critical item, especially with active solar energy systems. A drainback system, for example, requires high caliber work in pipe installation; pipe slope is crucial, and if the piping does not slope properly, the system will not drain, and freeze damage can be expected.
5. Final Inspection - The project manager, either directly or through a designated representative (Inspector),

shall perform a final inspection when installation of the system is essentially complete. The final inspection ascertains that the system has been installed as shown on the construction documents, that all previously noted problems have been corrected, and that the system is complete. This is an in-depth inspection, and the inspector shall prepare a final, written punch list for the contractor that details all items to be corrected. The inspector shall ensure that all corrective action items on the punch list are completed and shall accept the system for workmanship and completeness of materials (all equipment installed properly).

6. Operational Test - The project manager, either directly or through designated representatives (project engineer, inspector, etc.), shall witness an operational test of the system that includes operation of the solar system in each possible mode of operation. This is not a performance test of the system, and acceptance is not based upon reaching a certain energy output from the collector array. This test shall only ensure that all equipment is functional and properly calibrated.

This test shall include items such as:

- a. Differential controller turns the solar loop pump on/off at the design differential temperature settings. Pump shall not short cycle.

- b. Pump is producing the required collector array flowrate as described in the Construction Documents (see Chapter VII - Instrumentation).
- c. Flow in the collector array is balanced properly.
- d. Drainback systems actually drain back when the solar loop pump is off.
- e. Mixing valves are mixing fluid streams to the proper temperature.

At this point, each separate component of the overall project has been addressed individually and progressively accepted. Representatives of the O & M workforce should be present for this test. Representatives should include one staff engineer and one member of the maintenance staff as a minimum.

7. Instructional Seminar - Before final acceptance but after a successful operational test and acceptance of the O&M manual, the contractor shall hold an instructional seminar for the O & M workforce. This seminar shall be conducted by knowledgeable personnel at the site. The O & M workforce shall be notified at least one week in advance of the date, time, and place of the seminar. Requirements of the seminar are detailed in Chapter X - Operations and Maintenance.

8. As-Built Drawings - Before Final Acceptance the contractor shall provide one set of reproducible drawings noting all changes to the original design required during construction.
9. Spare Parts - Required spare parts, as detailed in Chapter X, shall be on-site.

### SYSTEM ACCEPTANCE CHECKLIST

ITEM	CHECK	
	YES	NO
1. Feasibility study completed and accepted. checklist completed	_____	_____
2. System selection completed and accepted	_____	_____
3. Schematic design completed and accepted	_____	_____
4. Design development completed and accepted	_____	_____
5. Construction documents completed and accepted	_____	_____
6. Instrumentation checklist completed	_____	_____
7. Design complete and accepted	_____	_____
8. Submittals for all required equipment have been accepted	_____	_____
9. All discrepancies, noted by inspection, have been corrected	_____	_____
10. A final inspection has been conducted	_____	_____
11. Operational test was conducted and accepted	_____	_____
12. O&M instructional seminar has been conducted	_____	_____
13. O&M Manual has been submitted and accepted	_____	_____
14. As-built drawings have been submitted and accepted	_____	_____
15. Spare parts required are on-site	_____	_____

\_\_\_\_\_ Initials

## CHAPTER X

### OPERATION AND MAINTENANCE

#### General

Operation and maintenance is crucial to the overall economics of the solar system. Although the designer may feel this is not part of the design process it does, in fact, have its basis in the system design. Throughout this manual, simplicity and, therefore, minimal maintenance have been emphasized in the design. Simplicity in design yields ease of operation and minimum downtime. In finalizing the project design, the designer should remember that system operators will not have been involved in the design and, therefore, are not aware of the designer's intent. A well defined control logic will help immensely in understanding system operation, but the following items shall be added to the construction documents, to be provided by the contractor:

- o Operating & Maintenance (O&M) Manual;
- o A complete set of operating instructions shall be posted in the mechanical room;
- o An instructional seminar, conducted on-site by knowledgeable personnel, for operators before final acceptance but after the operational test and acceptance of the O&M manual;
- o List of required spares to be provided.

1. O&M Manual

The O&M Manual shall contain, as a minimum:

- o A comprehensive set of system operating instructions for the user;
- o Trouble-shooting guide;
- o A preventive maintenance checklist; and
- o Catalog cut sheets for all equipment, including the name of the supplier, a parts list, and warranty data.

The O&M Manual shall be submitted for review to the project manager and must be accepted before the instructional seminar and final acceptance.

2. Instructional Seminar

The contractor shall provide an instructional seminar for the O & M workforce personnel before final acceptance.

This seminar shall be conducted by knowledgeable personnel and include, as a minimum

- o Start-up and operation of the system;
- o Filling and draining procedures;
- o Operation of the system controls;
- o Troubleshooting of the system;
- o Replacing sensors and/or other controls;
- o Detailed review of the O&M manual; and,
- o Scheduled maintenance (preventive).

### 3. Spare Parts

The designer shall require the following spare parts be supplied as part of the contract. These parts shall be on-site before final acceptance:

- o One (1) control unit (solid-state, off-the-shelf);
- o Four (4) control sensors of the same manufacturer;
- o One (1) set of solar loop pump seals and thrust bearings;
- o One (1) collector row PRV, preset;
- o One (1) thermometer to fit thermometer wells;
- o Two (2) percent collector glazings and glazing gaskets;
- o One (1) percent complete collectors (boxed);
- o One (1) complete refill of solar loop fluid, other than tapwater, in sealed and marked containers; and,
- o One (1) flow control device for collector rows, if used.

### 4. Operational Check

At least twice per month, and preferably weekly, maintenance personnel shall perform an operational check. This consists basically of observing that the system is functioning and that minimal operating parameters are being met. This operational check should not require more than 15-20 minutes each time. Operational checks should be performed at various times during which all aspects of operation, such as start-up



and shutdown are being checked. These are discussed below. Refer to the troubleshooting section if a problem is found.

1. Normal operation:

A check of normal operation should be made at midday under clear or fairly clear sky conditions (relative to locale). At midday, with clear sky conditions, the system should be collecting energy if a load exists. This can be ascertained by simply determining if the solar loop pump is operating. If so, the following quick checks shall be made:

- a. Using the digital or analog display of the differential controller determine the collector temperature.
- b. Using the digital or analog display determine the storage temperature.
- c. Subtract storage temperature from collector temperature. The differential shall be greater than the differential "off" setting.
- d. If item C. above is yes, the next step is to check the solar loop flowrate using the visual flowmeter or pressure differential. The flowrate should be within  $\pm 10\%$  of normal flow.
- e. Check the storage tank temperature to determine if it is above the high limit setpoint of the control logic (usually 180°F). The solar loop should not be operating if it is.
- f. Determine that heat exchangers and/or mixing valves are operating.

This normal operation check should be made at every other visit. That is, if weekly operational checks are made, then every other week should be a "normal operation" type check.

2. Start-up check:

This type of check should be made to determine if the system is starting properly. The check must obviously be performed in the morning when the system first starts and the specific time can only be determined by experience:

- a. Prior to the solar loop pump starting, check the collector and storage tank temperatures using the digital or analog display controller and determine the differential.
- b. Continue this procedure and confirm that the solar loop pump starts when the control logic "on" differential is reached.
- c. Perform checks d. through f. of Item #1 above.

3. Shutdown check:

This check is made to determine if the system is shutting down properly. Again, the approximate time of shutdown is determined by experience. Steps to be followed are:

- a. Prior to system shutdown (solar loop pump "off"), start checking the collector/storage temperature differential using the digital or analog display controller.
- b. Ascertain that the pump shuts down when the control logic "off" differential is met.

- c. If it is a drainback system insure that drainback occurs when the pump is deactivated.

4. Adverse weather:

An occasional check of the system should be made during adverse weather conditions. During extremely heavy cloud cover conditions, the system should not be operating. Note that the system may operate intermittently during light cloud conditions because of diffuse energy being collected.

Operational checks #2, 3 and 4 should be intermixed with check #1 on a scheduled basis with #1 occurring every other time (assuming adverse weather conditions do not preclude this).

5. Scheduled Maintenance (Preventive)

This item shall be the responsibility of the Facilities Engineering maintenance personnel. At intervals of six months minimum, the maintenance personnel shall:

- a. Wash the exterior glazing surface of the collectors, if needed, with compounds approved by the manufacturer.
- b. Inspect absorber plates for degradation (do not remove glazing).
- c. Inspect glazing gasket for damage. Replace worn or damaged gaskets.
- d. Inspect collector supports. Tighten or replace loose or missing hardware.

- e. Inspect valves, fittings, and piping for leaks.  
Repair as necessary.
- f. Test PRVs on collector rows. Replace defective units.
- g. Bleed air from closed loop systems.
- h. Inspect sensors. Replace defective units.
- i. Inspect pipe insulation and jacket. Replace degraded material as required.
- j. Inspect and lubricate pumps. Repair as needed.
- k. Inspect storage tank for leaks. Repair or replace.
- l. Verify operation of control unit per O&M manual.
- m. Test calibration of control sensors per O&M manual.
- n. Test drainback operation of system (open loop).
- o. Verify that solar loop and storage tank have fluid.

#### 6. Fluid Test

At intervals of 18 months to two years, maintenance personnel shall obtain a sample of the solar loop fluid from all glycol based systems. An analysis shall be performed to determine:

- a. Percentage, by weight, of glycol in the fluid. This should be approximately  $50\% \pm 5\%$ .
- b. Condition of corrosion inhibitors in the fluid.

#### 7. Troubleshooting

This troubleshooting guide covers the general areas of troubleshooting for a variety of systems. Maintenance personnel should first consult the troubleshooting section of the supplied O&M manual for the specific system

they are using. For existing systems that do not have a complete O&M manual, this troubleshooting guide can be used.

Troubleshooting a system implies that a problem has been encountered and the cause must now be determined. Since this manual is based upon standard or "generic" systems and keeping designs as simple as possible, the troubleshooting of these systems is also fairly simple and standard. The use of this troubleshooting section is based upon discovery of a malfunction during one or more of the operational checks detailed in Section 4. Therefore, the logic of the troubleshooting procedure is based upon the type of operational check performed (normal, start-up, shutdown, etc). The troubleshooting guide is also based upon use of a solid-state, digital display, differential controller as the primary diagnostic tool. In those systems where a solid-state controller with 10K ohm thermistor sensors, but without digital display being used, the temperatures being sensed must be determined using an ohm meter. For 10K ohm thermistors, the equivalent temperature for various resistance readings is given in Table IX.

Existing systems using custom-built control systems, especially pneumatic type controls, cannot readily be checked using this guide; each is a special case. To troubleshoot this type of system the user must obtain

TABLE IX  
TEMPERATURE VS RESISTANCE (°F VS OHMS)  
10,000 ohm Thermistor @ 77°F

°F	OHMS	°F	OHMS	°F	OHMS	°F	OHMS
32.0	32660	79.0	9626	131.0	2986	177.0	1234
33.0	31748	80.0	9299	132.0	2925	178.0	1212
34.0	30864	81.0	9077	133.0	2866	179.0	1191
35.0	30008	82.0	8862	134.0	2808	180.0	1170
36.0	29178	83.0	8657	135.0	2751	181.0	1149
37.0	28375	84.0	8453	136.0	2696	182.0	1129
38.0	27596	85.0	8250	137.0	2642	183.0	1109
39.0	26840	86.0	8048	138.0	2589	184.0	1090
40.0	26109	87.0	7847	139.0	2538	185.0	1071
41.0	25400	88.0	7647	140.0	2488	186.0	1052
42.0	24711	89.0	7448	141.0	2438	187.0	1034
43.0	24045	90.0	7250	142.0	2390	188.0	1016
44.0	23399	91.0	7053	143.0	2343	189.0	999
45.0	22771	92.0	6857	144.0	2297	190.0	982
46.0	22162	93.0	6662	145.0	2253	191.0	965
47.0	21572	94.0	6468	146.0	2209	192.0	948
48.0	21000	95.0	6275	147.0	2166	193.0	932
49.0	20444	96.0	6083	148.0	2124	194.0	916
50.0	19906	97.0	5892	149.0	2083	195.0	901
51.0	19382	98.0	5702	150.0	2043	196.0	886
52.0	18875	99.0	5513	151.0	2003	197.0	871
53.0	18382	100.0	5325	152.0	1965	198.0	856
54.0	17904	101.0	5138	153.0	1928	199.0	842
55.0	17440	102.0	4952	154.0	1891	200.0	828
56.0	16990	103.0	4767	155.0	1855	201.0	814
57.0	16552	104.0	4583	156.0	1820	202.0	800
58.0	16127	105.0	4400	157.0	1786	203.0	787
59.0	15715	106.0	4218	158.0	1752	204.0	774
60.0	15314	107.0	4037	159.0	1719	205.0	761
61.0	14925	108.0	3857	160.0	1687	206.0	749
62.0	14547	109.0	3678	161.0	1656	207.0	737
63.0	14180	110.0	3500	162.0	1625	208.0	725
64.0	13823	111.0	3323	163.0	1595	209.0	713
65.0	13476	112.0	3147	164.0	1565	210.0	701
66.0	13139	113.0	2972	165.0	1536	211.0	690
67.0	12812	114.0	2798	166.0	1508	212.0	697
68.0	12494	115.0	2625	167.0	1481		
69.0	12185	116.0	2453	168.0	1453		
70.0	11884	117.0	2282	169.0	1427		
71.0	11592	118.0	2112	170.0	1402		
72.0	11308	119.0	1943	171.0	1376		
73.0	11031	120.0	1775	172.0	1351		
74.0	10763	121.0	1608	173.0	1326		
75.0	10502	122.0	1442	174.0	1303		
76.0	10248	123.0	1277	175.0	1279		
77.0	10000	124.0	1112	176.0	1256		
78.0		125.0	948				

the system control logic, control layout, and any other data possible from the original contractor. The basic steps outlined herein could then be used as a very general guide.

The first steps to be taken in troubleshooting the system is determining the problem. Is the system not operating at all or is it just not starting at the proper time or is it not turning off at all? Fig. 35 shows a logic flow chart for the basic steps to be taken if a system is discovered not to be operating during a normal operating check. Keyed notes are shown for each step, that describe, in greater detail, action to be taken in each case. Fig. 36 and 37 are similar flow charts for start-up and shutdown with keyed notes are also provided. Fig. 38 is a logic chart for checking the load interface. A malfunction in the interface can manifest itself as a problem with the solar system.

As you will note, the majority of problems will most likely be control related. It will also be noted that when the problem is with the controller itself, the solution required is to simply replace the unit. This type of controller can be replaced completely for less cost than the maintenance time required simply to find the problem with a custom control system. Since a control unit is required as a spare part for these systems, this replacement is quickly accomplished and the malfunctioning

unit can be returned to the factory for repair and be used as the new spare.



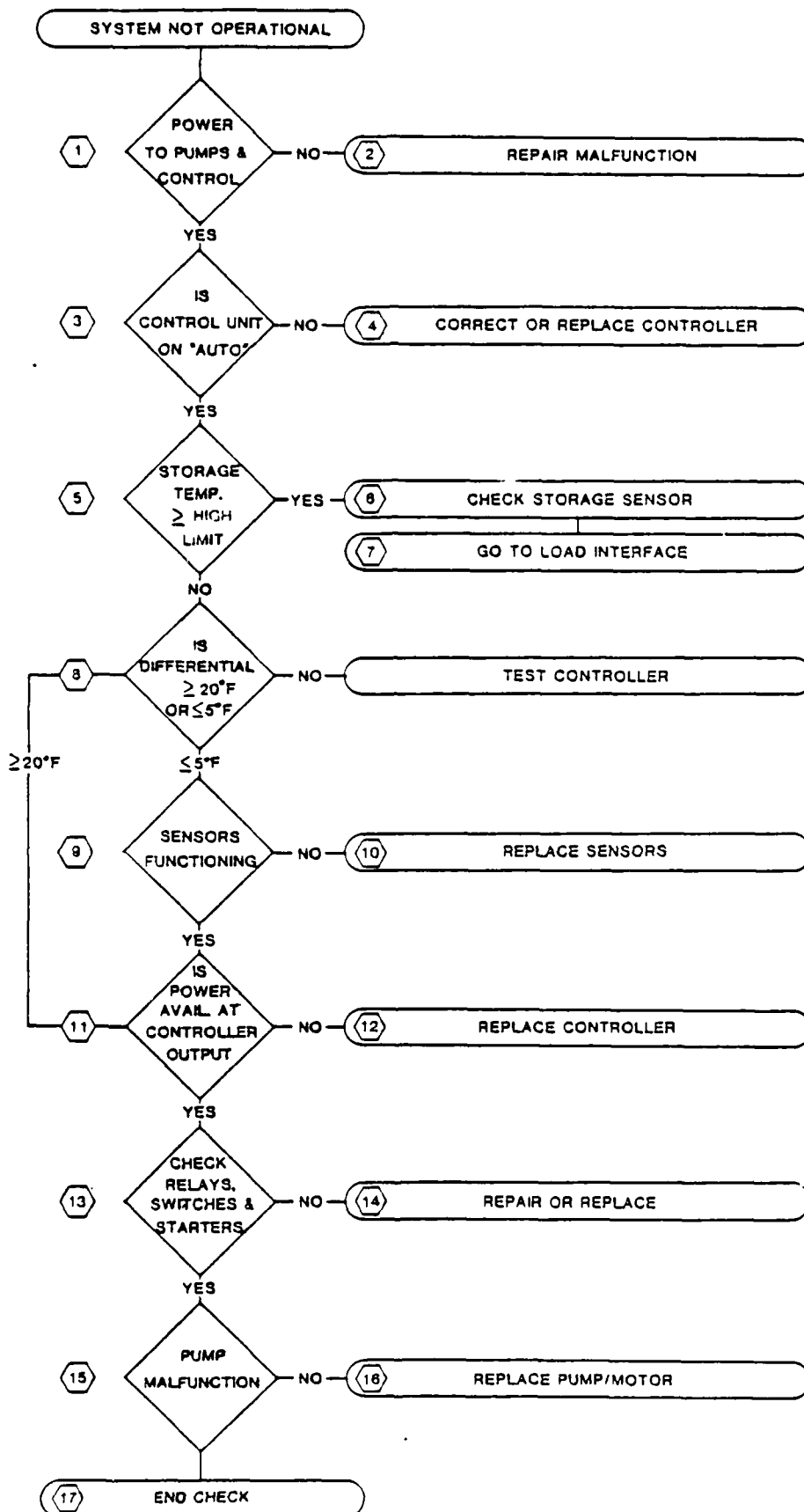


FIG. 35 - TROUBLESHOOTING LOGIC/NORMAL OPERATIONAL CHECK

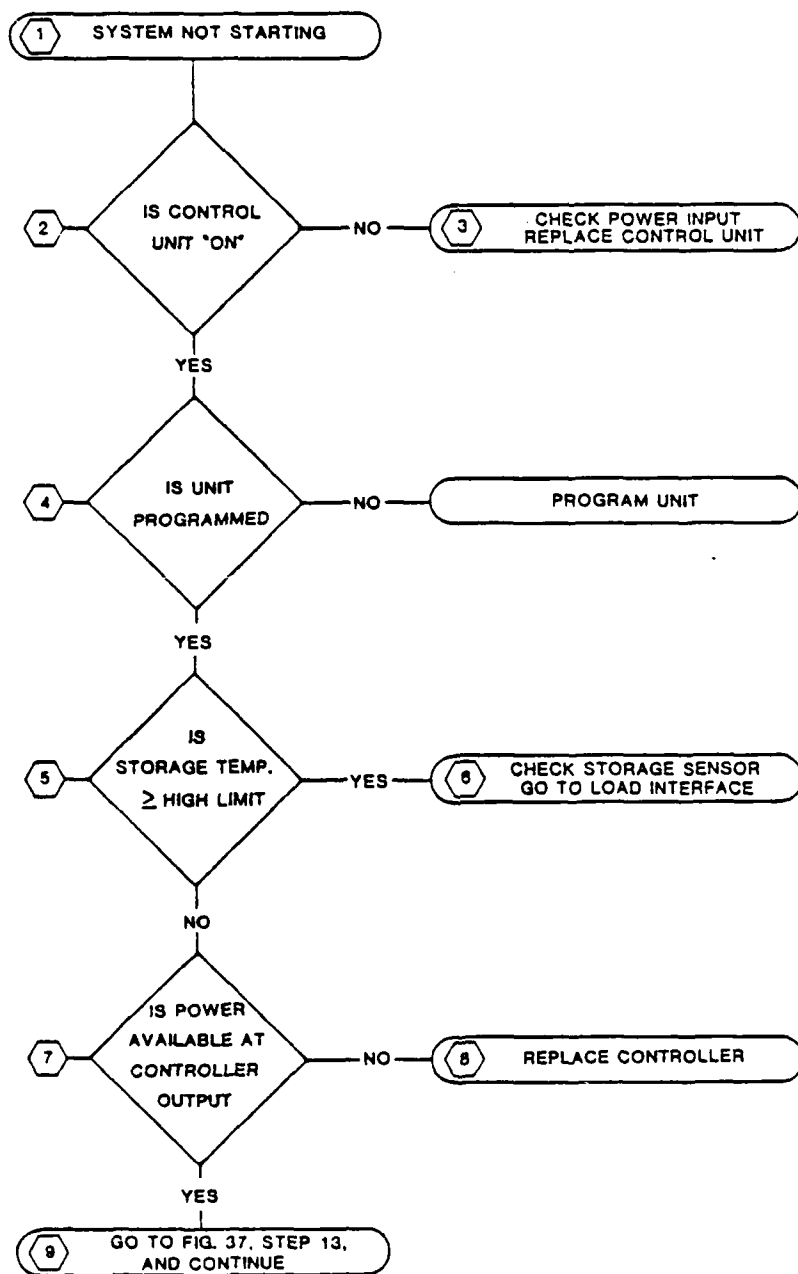


FIG. 36 - TROUBLESHOOTING LOGIC/SYSTEM NOT STARTING

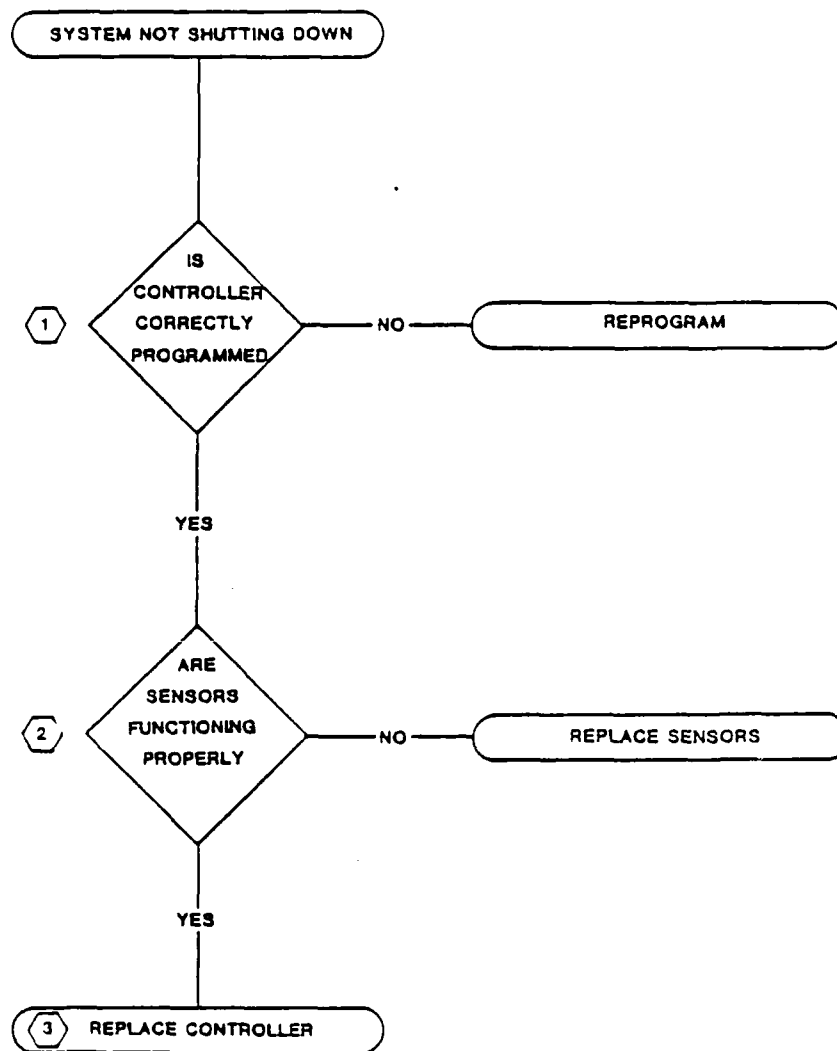


FIG. 37 - TROUBLESHOOTING LOGIC/SYSTEM NOT SHUTTING DOWN

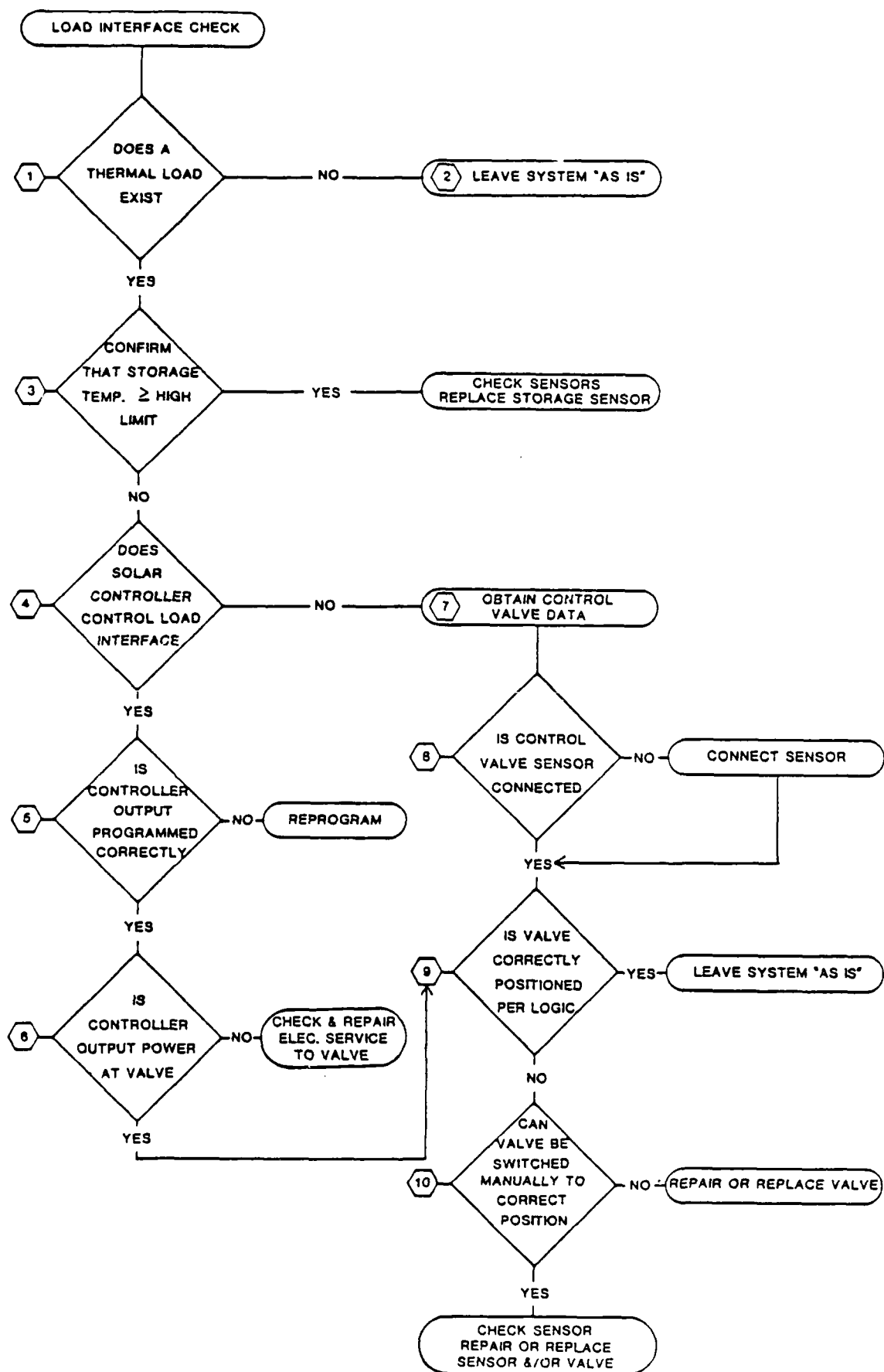


FIG. 38 - TROUBLESHOOTING LOGIC/LOAD INTERFACE

## KEYED NOTES - FIG. 35

1. Check system power sources. Ensure that all circuit breakers and disconnect switches are on. Check electrical subpanels feeding solar equipment. Determine that the required power is available at the pump or the service side of pump control relays. Determine that power is available to the control unit (input side). Use test equipment to confirm this.
2. If power service has been interrupted, replace or correct malfunctioning equipment. If required, initiate work order for action by appropriate trade.
3. Determine if the system control unit is "on". If the unit has a selector switch for ON-OFF-AUTO, ensure that it is in the AUTO position.
4. If the controller is not "on", check unit internal fuses if possible (see controller cut sheets in O&M manual). If unit cannot be activated, replace controller and send malfunctioning unit to manufacturer for repair.
5. Using the control unit digital or analog display, check the solar storage tank temperature. If the temperature is greater

than or equal to the high limit setting the solar loop pump should be "off". For most systems, this setting will be 180°F. If the control unit has an adjustment for the high limit or is programmable, check the setting to determine if the control unit setting agrees with the system control logic. If the high limit setting is not correct, reset the high limit to the proper value.

6. If the storage temperature is above the correct high limit setting, confirm the storage sensor reading by checking the mercury thermometer installed in the storage tank. The thermometer should read within  $\pm 10^\circ\text{F}$  of the sensor reading. If not, replace storage tank sensor and recheck per note #5.
7. If the storage tank is above the high limit setting and the storage sensor is functioning properly go to the Load Interface check, Fig. 38 to check for proper functioning. Unless the solar system is oversized, the storage tank should only exceed the high limit on rare occasions.
8. Compare the collector temperature and storage temperature using the display of the control unit. If the differential is  $\geq 20^\circ\text{F}$  ( $8^\circ\text{F}$  for direct systems), the solar loop pump should be on. If the differential is  $\leq 5^\circ\text{F}$  ( $3^\circ\text{F}$  for direct systems), the solar loop pump should be off. If the differential is  $\geq 20^\circ\text{F}$  ( $8^\circ\text{F}$ ) and the

pump is off, skip the sensor check and go to step #10. If the differential is  $\leq 5^{\circ}\text{F}$  ( $3^{\circ}\text{F}$ ), the pump should be checked per the next step. If the differential falls between the  $20^{\circ}\text{F}$  ( $3^{\circ}$ ) "off" setting the following test should be made:

- a. Remove one connection to "storage" input on the control unit. The control unit will interpret this as being  $32^{\circ}\text{F}$  and should create a situation where the differential is  $>20^{\circ}\text{F}$  ( $8^{\circ}\text{F}$ ).
- b. The pump should activate when this open circuit is created. Confirm start-up of the pump.
- c. If the solar loop pump does not start go to the next step.

9. Using the digital or analog display of the controller, a hand-held ohm meter, and the thermometers installed in the collector rows and storage tank, confirm the temperatures indicated by the sensors. A variation between the displayed value (controller) vs. the ohm meter and/or thermometer of  $\pm 10^{\circ}\text{F}$  is acceptable.
10. If sensors are found to be faulty, replace the sensor in question. Sensors from the controller manufacturer should be used in all cases. Continue to the next step if sensors are functioning.

11. Determine if power is available at the output of the control unit for a pump "on" situation. If the differential is correct and the high limit is not exceeded, the output should be "hot".
12. If output power is not available and should be, replace the control unit and return malfunctioning unit to manufacturer for repair. Recheck all operations with new unit.
13. If a pump "on" situation exists and power is available at the controller output, but the pump is not functioning, check all relays, contactors, magnetic starters, disconnects and HAND-OFF-AUTO switches in the pump circuit.
14. If a malfunction is found, repair or replace the defective component.
15. If a pump "on" situation exists, and power is being delivered to the pump motor, the pump should be operating. If not, the pump and/or motor has malfunctioned. Determine defective unit or units.
16. Replace motor, pump or both as required.
17. End troubleshooting guide.



## KEYED NOTES - FIG. 36

1. It is assumed that during a start-up operational check, it was found that the system did not begin operation when the differential temperature between collector and storage reached the "on" point (20°F or 8°F). It is also assumed that since the sensors are reading temperature changes for the differential, that they are functional.

If the sensors do not show an increasing collector temperature or a realistic storage temperature, go to Fig. 35, step #9.

2. If the control unit has a selector switch for ON-OFF-AUTO, ensure that it is in the AUTO position. If the unit does not have a switch, it should have an indicator light.
3. Check system power sources. Ensure that circuit breakers and disconnects are engaged. Determine that power is available at pump control relays. Check input power to control unit. Replace malfunctioning electrical equipment. If control unit has power but does not come "on", replace control unit.

4. If unit is programmable, ensure that all programming switches are in the proper positions.
5. Determine if storage temperature is above the high limit setting of the control logic using the digital display of the control unit.
6. If the controller indicates a storage temperature above the high limit, cross-check the sensor reading using the storage tank thermometers. If the sensor is not reading properly ( $\pm 10^{\circ}\text{F}$ ), replace the storage sensor. If the storage sensor is correct, go to Fig. 38 - Load Interface.
7. Determine if power is available at the output of the control unit. On small systems, this will feed the pumps and/or valves directly; on larger systems control relays will interface with the pump.
8. If output power is not found, replace the control unit and send malfunctioning unit to manufacturer for repair.
9. If control output is found and pump is not operating, go to Fig. 35, step #13 and continue.

## KEYED NOTES - FIG. 37

1. If the differential controller is programmable or on/off settings are adjustable, ensure that the programming is correct. See controller data for adjustment or programming information.
2. Using the digital display, check the collector and storage sensors. Compare sensor readings with thermometer readings for each. If sensors are not within  $\pm 10^{\circ}\text{F}$  of thermometers, replace sensors. Ensure that sensors are properly attached before replacing.
3. If programming is correct, sensors are functioning properly and pump does not shutdown, replace control unit and send malfunctioning unit to manufacturer for repair.

## KEYED NOTES - FIG. 38

1. Determine if a thermal load for the system exists. If not, the thermal capacity of the storage tank may be at its maximum and the system has shutdown.
2. Leave system "as-is" and recheck when thermal load is present.
3. Determine if storage tank temperature is  $\geq$  high limit setting. Ensure that the correct high limit setting is used. If sensor indicates that storage is above correct high limit setting, cross-check sensor reading with storage thermometer to determine if sensor is reading properly. Replace sensor if  $\pm 10^{\circ}\text{F}$  different.
4. Determine if load interface is controlled by solar system controller or if it is a stand-alone control. If the load interface is stand-alone, go to step #7.
5. If the controller is adjustable or programmable, determine if proper settings are used (use control logic). If not, adjust to correct settings or reprogram.
6. Determine if the control unit output to the load interface should be on at this time using the system control logic. If so, check the output of the controller for the required

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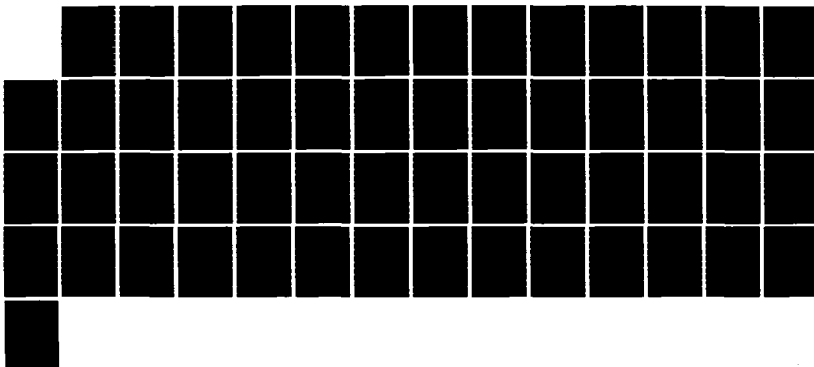
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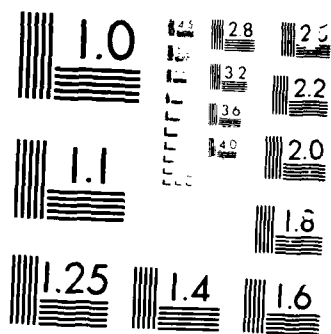
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power to the controlled equipment. Jumper or open sensor inputs to create an "on" condition if necessary. If power is not available at the controlled equipment, check wiring and/or relays between the units and repair if necessary. If the power is not available at the controller output, replace the control unit.

7. Obtain data from O&M manual for operation of load interface equipment.
8. Determine if sensors for control valve (not solar control unit sensors) are properly installed and connected. If not, repair or replace sensor or connection as required.
9. Determine if the control valve is properly positioned (opened, closed, port A to B, etc.) for the control logic conditions existing. If yes, leave system "as-is" and recheck under other thermal load conditions.
10. If the valve position is not correct, can the valve status be changed manually by inducing different control signal? If not, the valve itself has probably malfunctioned and will have to be repaired or replaced. If the valve can be repositioned manually, control connections, relays and/or solenoids should be checked and repaired. Replace valve if all connections are correct.

## CHAPTER XI

### PACKAGED DHW SYSTEMS

#### General

This chapter is devoted to the selection of packaged DHW systems not the design. The packaged systems, as defined in this manual, are considered to be commercially available, off-the-shelf systems in which all major components, such as collectors, tanks, pumps, and controls are pre-engineered and are part of the package. In selecting a packaged DHW system, the following general criteria must be adhered to by the designer:

1. A single, packaged system shall not be used for more than two residences or apartments.
2. Total DHW demand shall not exceed 120 gal. per day per Appendix A at a 120°F demand temperature.
3. Packaged DHW systems shall not be ganged together to meet a load. Packaged systems must operate separately.
4. The selected packaged DHW system must meet the criteria for selection defined in this manual.
5. Failure to meet the above criteria requires that the designer return to Chapter I - System Selection and determine the correct system to be designed.



For this manual, system selection will be based on the size of the DHW storage tank required; all other parameters will be defined from this point. In keeping with the philosophy of this manual regarding standardized systems, only three storage tank sizes are allowed. These are 60, 80 and 120 gal. (approximate).

### Size Selection

Selection of one of the three system sizes allowed will be based on the criteria shown in Table X. For small commercial DHW loads, such as a small office building with restrooms only, a packaged system should be used if the DHW demand is equal to or less than 120 gal. per day as determined using Appendix A of this manual.

**TABLE X**  
**PACKAGED DHW SIZE SELECTION**

APPLICATION	SYSTEM SIZE (Tank size in gal.)
One apartment-one bedroom	60
Two apartments-one bedroom	80
One apartment-multi bedroom	80
Two apartments-multi bedroom	120
One residence-two bedroom	80
One residence>two bedroom	120
Two residences (duplex)	120
Commercial, demand $\leq$ 60 gal.	60
Commercial, 60 gal. < demand $\leq$ 80 gal.	80
Commercial, 80 gal. < demand $\leq$ 120 gal.	120
Commercial, demand > 120 gal.	Not Applicable Return to System Selection

The 60, 80 and 120 gal. tank sizes given are approximate. It is not intended to eliminate tanks such as 82 gal. or 115 gal. Acceptable systems can have tanks sized to  $\pm 10\%$  of the three standard sizes shown. Therefore, a packaged system with a DHW tank between 54 and 66 gal. could be selected for the 60 gal. size system.

#### Packaged DHW System Types

Three types of systems are allowed for selection. These systems basically correspond to the generic types discussed in Chapter 1 for designed systems. These are:

- o Closed loop glycol systems (antifreeze);
- o Drainback; and
- o Direct recirculation.

The scope of this manual addresses only active, liquid solar systems at this time. Packaged DHW systems of the passive, batch type, or phase change heat transport (vaporized refrigerant) type are, therefore, not considered. This does not imply that these DHW system types are not good choices also but simply that they are not within the scope of this manual.

#### System Descriptions

Packaged DHW systems, within the types allowed shall have, as a minimum, the following components as part of their package. No exceptions are allowed:

#### Closed loop glycol:

- o Collectors with supports;
- o Pressurized DHW tank, insulated and lined, with auxiliary back-up heating;
- o Double wall heat exchanger with leak detection;
- o Pumps (2), centrifugal, 120 VAC, single phase, 60 hertz;
- o Controller, differential type, solid-state with 10K ohm thermistor sensors; and
- o Glycol fluid with inhibitors, 50% mix by weight.

#### Drainback:

- o Collectors with supports;
- o Pressurized DHW tank, insulated and lined, with auxiliary back-up heating;
- o Drainback tank, insulated;
- o Heat exchanger, exterior or in drainback tank;
- o Pumps (2), centrifugal, 120 VAC, single phase, 60 hertz;
- o Controller, differential type, solid-state with 10K ohm thermistor sensors; and
- o Vacuum breaker.

#### Direct Recirculation:

- o Collectors with supports;
- o Pressurized DHW tank, insulated and lined, with auxiliary back-up heat;
- o Pump (1), centrifugal, 120 VAC, single phase, 60 hertz; and,

- o Controller, differential type, solid-state with 10K ohm thermistor sensors.

The designer shall also require the contractor to provide the following for all systems as part of installation:

- o PRV at collector and DHW tank, vent per code requirements;
- o Manual air vent on collector outlet;
- o All piping shall be type "L" copper with silver or 95/5 soldered joints;
- o All piping insulated per Chapter V of this manual;
- o All sensors to be installed per Chapter V of this manual;
- o A three-way mixing valve (also called tempering valve), thermostatically controlled, shall be installed on the outlet of the solar DHW tank set at not greater than 120-125°F to prevent scalding;
- o All piping in other than closed loop glycol solar loop to be disinfected per code;
- o Furnish and install mercury type thermometers, in wells, at the following locations:
  - a. Collector supply line,
  - b. Collector return line, and
  - c. Mixed fluid outlet of mixing valve (tempering valve).
- o Fill/drain connection for solar loop;
- o All major components of the system shall be valved using appropriate sized ball valves. This shall include collectors, control/heat exchanger module, storage tank, pumps (if separate from module), and drainback tanks; and,

- o Dielectric couplings shall be used for connection of all dissimilar metal fluid lines.

#### System Component Requirements

The basic types, sizes and general requirements of packaged DHW systems have been defined. This section defines the criteria for the various major components of packaged systems that must be met. All components of any packaged DHW system considered shall meet these requirements.

#### Collectors:

- o Single glaze, selective surface. The selective surface shall be electroplated or chemically deposited (painted surfaces not acceptable) with a minimum absorptivity of 0.90 and a maximum emissivity of 0.15;
- o Copper fluid passages (risers), copper tube with aluminum fin allowed;
- o Mounting of collector shall not require drilling of collector box assembly;
- o Absorbers and headers shall not be rigidly attached to collector box to allow for expansion; and
- o Collector box shall be metal, protected from corrosion.

#### Collector Supports:

- o Collector supports shall be a premanufactured item and not site built (site assembly permitted);
- o Supports shall be of steel or aluminum construction, no wood shall be used;

- o Supports shall be rigidly attached to structures or ground by anchoring. Weighting of supports is not permitted; and,
- o Supports shall be structurally sound and capable of withstanding a minimum 80 mph wind and, in no case, less than the local design wind conditions.

#### Storage Tank:

- o Sizes as stated;
- o ASME pressure rated;
- o Insulated;
- o Glass, copper, stone or cement lined;
- o Back-up electrical heating element(s); and
- o At least one (1) In-tank temperature sensor or sensor well. Preinstalled sensors shall be 10k ohm thermistor type.

#### Pumps:

- o Centrifugal, 120 VAC, single phase, 60 hertz;
- o Brass, bronze, or bronze-fitted for wetted surfaces; and
- o Off-the-shelf unit.;

#### Controllers:

- o Solid-state, differential control unit with 10K ohm thermistor sensors;
- o 120 VAC, single phase, 60 hertz input/ output;
- o High limit setting not to exceed 180°F;

- o Shall have on/off indicator and/or on-off-auto switch;  
and,
- o Controller shall be accessible without shutting down  
system if contained in a control module.

Heat Exchanger: (not applicable to direct recirculation)

- o Double walled with leak detection;
- o All wetted surfaces shall be copper or stainless steel  
construction; and
- o Shall be of sufficient size to transfer the maximum  
possible energy the system can collect.

Drainback Tank:

- o Shall be capable of storing entire fluid content of solar  
loop;
- o Insulated;
- o Drainable; and
- o Shall be installed in heated space only.

#### COLLECTOR SIZING

Packaged DHW systems are to be selected on the basis of storage tank size. For each size selected, a minimum collector area shall be required. These are given in square feet of aperture area.

60 gal. tank - 30 sq. ft.

80 gal. tank - 39 sq. ft.

120 gal. tank - 60 sq. ft.

This is essentially the same sizing ratio of storage volume to collector area used in the design of larger commercial systems.

### Operating and Maintenance

Packaged DHW systems operate almost identically to the large commercial systems of the same type. Maintenance requirements are also similar but usually less complicated. Maintenance time is normally less, on a relative scale, because problems have been eliminated in previous systems sold. However, total maintenance time for packaged systems totalling 1,000 sq. ft. is greater than for a single 1,000 sq. ft. system (more pumps, controllers, sensors, etc.).

In finalizing projects using packaged DHW systems, the designer must realize that the packaged system is treated just like any other piece of equipment. Design requirements must, therefore, be provided in concise detail in the packaged system specification. With regard to operating and maintenance of the packaged system, the designer shall require the contractor to provide the following as part of the system:

- o Operating & Maintenance (O&M) Manual;
- o A complete set of operating instructions shall be posted next to the DHW control unit or module;
- o An instructional seminar shall be conducted on-site by knowledgeable personnel for housing managers, housing inspectors and housing maintenance personnel before final acceptance but after a successful operational test and acceptance of the O&M manual; and
- o Parts list.



The O&M Manual shall contain the following minimum information:

- o A comprehensive set of system operating instructions written for a lay person;
- o Trouble-shooting guide and preventive maintenance checklist; and
- o Catalog cut sheets, name of the manufacturer, parts list, and warranty data.

The O&M Manual shall be listed as a required submittal.

The contractor shall provide an instructional seminar for operating personnel before final acceptance. This seminar shall be conducted by knowledgeable personnel and include, as a minimum:

- o Start-up and operation of the system;
- o Filling and draining procedures;
- o Operation of the system controls;
- o Troubleshooting of the system;
- o Replacing sensors and/or other controls;
- o Detailed review of the O&M Manual, and
- o Schedule maintenance (preventive).

#### Operational Checks:

At least twice per month, and preferable weekly, housing inspectors or maintenance personnel shall perform a simple operational check of the system. This consists basically of

observing that the system is functioning and that certain minimal operating parameters are being met. This operational check should not require more than 15-20 minutes each time.

Operational checks should be performed at various times during the day and during adverse weather conditions so that all aspects of operation, such as start-up and shutdown are being checked. These are discussed below. Refer to the troubleshooting section of Chapter X if a problem is found during any check performed.

#### 1. Normal Operation:

A check of normal operation should be made at midday under clear or fairly clear sky conditions (relative to locale). At midday, with clear sky conditions, the system should be collecting energy if a load exists. This can be ascertained by simply determining if the solar loop pump is operating. If so, the following quick checks shall be made to determine if operation is within the parameters of the control logic:

- o Check the mercury thermometers installed on the solar supply and return lines. The line from the collectors (SHWS) should be at least 3°F greater than the return line;
- o Check the solar storage tank temperature. If it is above 180°F the system should be off. If not, manually shut the system down and refer to the troubleshooting guide in Chapter X; and
- o Check the thermometer on the mixed fluid outlet of the mixing valve; it should not be above 125-130°F maximum.

If it is, repair or replace the valve.

This normal operation check should be made at every other visit. That is, if weekly operational checks are made, then every other week should be a "normal operation" type check (assuming weather conditions permit).

## 2. Start-up Check:

This type of check should be made to determine if the system is starting properly. The check must obviously be performed in the morning when the system first starts and the specific time can only be determined by experience. The following steps should be followed:

- o Prior to the solar loop pump starting, check the collector and storage tank temperatures using an ohm meter (see Chapter X) on the 10k thermistors and determine the temperature differential; and
- o Continue this procedure and confirm that the solar loop pump starts when the control logic "on" differential is reached.

## 3. Shutdown Check:

This check is made to determine if the system is shutting down properly per the system control logic specified. Again, the approximate time of shutdown is determined by experience. Steps to be followed are:

- o Prior to system shutdown (solar loop pump "off"), start checking the collector/storage temperature

differential using an ohm meter;

- o Ascertain that the pump shuts down when the control logic "off" differential is met; and
- o If it is a drainback system, ensure that drainback occurs when the pump is deactivated.

#### 4. Adverse Weather:

An occasional check of the system should be made during adverse weather conditions. During extremely heavy cloud cover conditions, the system should not be operating. Note that the system may operate intermittently during light cloud conditions because of diffuse energy being collected.

Operational checks "2, "3, and "4 should be intermixed with check #1 on a scheduled basis, with #1 occurring every other time (assuming adverse weather conditions do not preclude this).

#### Scheduled Maintenance: (Preventive)

At intervals of six months minimum, responsible personnel shall:

- a. Wash the exterior glazing surface of the collectors, if needed, with compounds approved by the manufacturer.
- b. Inspect absorber plates for degradation (do not remove glazing).
- c. Inspect glazing gasket for damage. Replace worn or damaged gaskets.
- d. Inspect collector supports. Tighten or replace loose or missing hardware.

- e. Inspect valves, fittings, and piping for leaks.  
Repair as necessary.
- f. Test PRVs on collector rows. Replace defective units.
- g. Bleed air from closed loop systems.
- h. Inspect sensors. Replace defective units.
- i. Inspect pipe insulation and jacket. Replace degraded material as required.
- j. Inspect storage tank for leaks. Repair or replace.
- k. Verify that solar loop has fluid and that storage has fluid.

#### 6. Fluid Test:

At intervals of 18 months to two years, obtain a sample of the solar loop fluid for all glycol based systems. An analysis shall be performed to determine the following:

- a. Percentage, by weight, of glycol in the fluid. This should be approximately  $50\% \pm 5\%$ .
- b. Condition of corrosion inhibitors in the fluid.

#### Troubleshooting:

Refer to Chapter X, Section 7 for troubleshooting of systems or refer to the system O&M manual.

#### SPARE COMPONENTS

It is assumed that purchases of packaged DHW systems will most likely encompass more than one system, except for a single, small commercial project. Therefore, required spare components are based upon the number of systems purchased as follows:

1-2 Systems:

- o One (1) glazing with gasket, boxed;
- o Two (2) sensors; and,
- o One (1) differential controller if not part of a control/heat exchanger module.

3-5 Systems:

- o Two (2) glazings with gaskets, boxed;
- o Four (4) sensors;
- o One (1) differential controller if not part of a control/heat exchanger module; and,
- o One (1) solar loop pump.

6-15 Systems:

- o Two (2) glazing with gaskets, boxed;
- o One (1) complete collector, boxed;
- o Six (6) sensors;
- o One (1) differential controller or one (1) complete control/heat exchanger module;
- o One (1) mixing (tempering) valve, preset;
- o One (1) fill of solar loop fluid, other than tapwater, in a marked, sealed container;
- o One (1) solar loop pump (if not part of module); and,
- o One (1) heat exchanger loop pump (if not part of module).

16-40 Systems:

- o Four (4) glazings with gaskets, boxed;
- o Two (2) complete collectors, boxed;
- o Ten (10) sensors;
- o One (1) roll ( $\geq$  100 ft.) of sensor lead wire;
- o Two (2) differential controllers or two (2) complete

control/heat exchanger modules;

- o Two (2) mixing valves, preset;
- o Two (2) PRV's, preset;
- o Two (2) fills of solar loop fluid, other than tapwater, in marked, sealed containers; and,
- o Two (2) solar loop and two (2) heat exchanger loop pumps (if not part of module).

41 + Systems:

- o Glazings with gaskets, boxed, = number of collectors x 0.10;
- o Complete collectors, boxed, = number of collectors x 0.05;
- o 12 sensors;
- o 100 ft. of sensor lead wire;
- o Four (4) controllers or modules;
- o Mixing valves and PRV's = number of systems x 0.10;
- o Solar loop fluid = number of systems x 0.05 (complete fills); and,
- o Pumps, each type = number of systems x 0.08.

# PACKAGED DHW CHECKLIST

ITEM	CHECK	
	YES	NO
1. System sizes are selected based upon Table VIII.	_____	_____
2. Systems are 60, 80 or 120 gal. ( $\pm 10\%$ )	_____	_____
3. Total DHW demand does not exceed 120 gal. per day	_____	_____
4. Systems are not ganged together	_____	_____
5. Packaged system are off-the-shelf catalog items	_____	_____
6. Systems are active, liquid type only	_____	_____
7. System type is closed loop glycol, drainback, or direct recirculation.	_____	_____
8. Controller is solid-state, differential with 10K ohm thermistors or nickel-platinum probes?	_____	_____
9. Heat Exchangers are double-wall with leak detection?	_____	_____
10. All required system components are included in selected system?	_____	_____
11. All additional items, required for installation, are specified (PRV's, etc)?	_____	_____
12. All component design criteria have been met?	_____	_____
13. Collector sizing for tank volume is correct?	_____	_____
14. O&M manual and instructional seminar required?	_____	_____
15. Required spares specified?	_____	_____

\_\_\_\_\_ Initials



## APPENDIX A

### LOAD CALCULATIONS

Load calculations required for systems addressed by this manual include the following:

- o Domestic Hot Water (DHW)
- o Industrial Process Heat (IPH)
- o Swimming Pools (SWP)
- o Space Heating (SH)
- o Space Cooling (SC)

Projects that may require solar energy systems will include both new and retrofit work. Requirements and recommendations for thermal load calculations will vary slightly, depending on the type of project as discussed below.

#### New Projects

New projects within the military construction system may require that a complete energy analysis of the project be performed using a main-frame computer code such as the BLAST program developed by CERL. In designing a solar system as part of these projects, load calculations from the computer analysis should be used to size and design the solar system for whatever application is required, such as DHW or SH. This will ensure consistency in equipment sizing and eliminate possible conflicts between the conventional HVAC and solar system designer.

Thermal load calculations for new projects that do not require complex, computerized energy analysis can be accomplished by any acceptable method the designer is experienced with. Suggested hand calculation methods for load analysis are contained in this appendix, but in the absence of a preferred method, the computer codes F-CHART, Version 5. and/or F-LOAD or the latest editions of each should be used to provide loads, especially for DHW, IPH or SWP applications.

### Retrofit Projects

Retrofit projects normally do require energy analysis using main-frame computer codes such as BLAST. If a main-frame computerized energy analysis is performed, however, these load calculations should be used for the same reasons stated previously.

In most cases, the solar system designer will be required to calculate the thermal loads directly and, again, any acceptable method the designer is experienced with can be used. For retrofit projects, the designer should also consider analysis of data regarding historical energy use, if it exists.

## HAND CALCULATIONS

### DHW Thermal Loads

Calculation of DHW loads by hand method is fairly straightforward and can be accomplished by the following method:

1. Calculate the total daily DHW usage for the project. This is normally done on the basis of gallons per person per day for projects

such as family housing, unaccompanied personnel housing (barracks), schools, and office building or gallons per meal per day for food establishments such as a cafeteria or mess halls. Table A-1 lists average DHW demands for a variety of applications.

2. Determine the DHW supply temperature required. The normal design temperature is 120°F for most applications and 140°F for most food establishments. The designer should note that the required 180°F water for dishwashing (sterilization) in food establishments is usually accomplished by booster heaters in the dishwasher. This will not always be the case in retrofit projects, and the designer should take care to determine this point.
3. Obtain the monthly average temperature for the incoming water service to the project from the local utility company or post/base engineering group responsible.

TABLE A-1  
AVERAGE DHW DEMANDS

TYPE OF BUILDING	AVERAGE DAY
Unaccompanied Enlisted Personnel Housing	.25 gal./person
B.O.C.'s (number of units):	
20 or Less	25.0 gal/unit
60	18.0 gal/unit
100 or More	15.0 gal/unit
Nursing Homes	18.4 gal/bed
Office Buildings	1.0 gal/person
Food Service Establishments	
Type A - Full meal restaurants, cafeterias, & messhalls.	2.4 gal/average <sup>a</sup> meals/day
Type B - Drive-ins, grillies, luncheonettes, sandwich & snack shops	0.7 gal/average <sup>a</sup> meals/day
Apartment Houses (number of apartments):	
20 or Less	42.0 gal/apartment
50	40.0 gal/apartment
75	38.0 gal/apartment
100	37.0 gal/apartment
Over 130	35.0 gal/apartment
Elementary Schools	0.6 gal/student <sup>a</sup>
Junior & Senior High Schools	1.8 gal/student <sup>a</sup>

<sup>a</sup>Per day of operation.

4. Determine the average differential temperature for each month of the year ( T ) based on the selected design temperature (from step 2) and the water temperature schedule obtained (step 3).
5. Calculate the DHW load by multiplying the calculated demand (step 1) times the differential temperature (step 4) as follows:

$$Q_{DHW} = m c_p DT$$

where

$Q_{DHW}$  = DHW load, BTU/day

M = DHW demand, lbs. of water/day

$C_p$  = specific heat of water = 1.0 BTU/lb·F

DT = differential temperature, °F

6. Multiply the calculated load of step 5 by the following factors to account for heat loss (approximate) from the conventional DHW system:
  - a. 1.05 - new construction, well insulated piping, no recirculation.
  - b. 1.10 - new construction, well insulated with DHW recirculation.
  - c. 1.15 - retrofit, no insulation, no recirculation.
  - d. 1.20 - same as c. with recirculation.

#### IPH Thermal Loads

Process heat systems are calculated in essentially the same manner as the DHW loads with the following exceptions:

1. Design temperatures are usually quite specific (set point), but the set point will vary according to the particular process.
2. Demand is normally well defined in gpm, gph, or gpd.
3. The process return temperature, usually quite specific as well, is used instead of entering water service temperature to determine the differential.
4. The process fluid may not be water, and the specific heat of the fluid must be ascertained.

#### Space Heating (SH)

The heating load is the quantity of heat which must be put into a space by a heating system to maintain a certain temperature in the space during cold ambient conditions. That is, the heat input to a space must offset the heat loss to the outdoors. Heat losses are classified as transmission losses and infiltration losses. Transmission losses are heat conduction through exterior walls, windows, ceilings and floors. Infiltration losses are the result of untempered outside air movement directly into the space through cracks or through open doors or windows.

In order to calculate the heat loss, the following information must be determined:

1. Outdoor design temperature. The designer should refer to an appropriate weather data source for the project location.

2. Indoor design temperatures for each room during the coldest weather.
3. Estimate temperatures in unheated rooms during design conditions.
4. Compute heat transfer coefficients for exterior wall, windows, and roof. Also, calculate heat transfer coefficients for any surfaces adjacent to unheated spaces such as garages, attics, crawlspaces or storage rooms.
5. Calculate areas for all surfaces which have heat loss. Each type of wall or window which has a different heat transfer coefficient should be noted separately. It is important that these calculations be done on a room by room basis.
6. Compute heat loads for each surface using the following formula:

$$\begin{aligned} \text{Heat loss [BTU/HR]} &= \text{Heat transfer coefficient } \frac{\text{BTU}}{\text{HRFT}^2 \cdot \text{F}} \\ &\quad \times \text{AREA [FT}^2\text{]} \\ &\quad \times (\text{Inside temp} - \text{outside temp}) [^{\circ}\text{F}] \end{aligned}$$

7. Compute heat losses from grade level slabs or basement walls by the following method. For grade level slabs, the loss is determined by:

$$\begin{aligned} \text{Heat Loss [BTU/HR]} &= \text{Exterior Perimeter [Ft]} \times F \\ &\quad [\text{BTU./Hr. Ft}] \end{aligned}$$

where, F is taken from Table A-2 and A-3. Calculating

**TABLE A-2**

**Heat Loss of Concrete Floors at or Near Grade Level  
Per Foot of Exposed Edge (less than 3 ft Below Grade)**

Outdoor Design Temperature, F	Heat Loss per Foot of Exposed Edge, [Btu/hr.ft]		
	R = 5.0 Edge Insul.	R = 2.5 Edge Insul.	No Edge Insul. <sup>a</sup>
-20 to -30	50	60	75
-10 to -20	45	55	65
0 to -10	40	50	60
+10 to 0	35	45	55
+20 to +10	30	40	50

<sup>a</sup> This construction not recommended; shown for comparison only.

**TABLE A-3**

**Floor Heat Loss to be Used When Warm Air Perimeter  
Heating Ducts Are Embedded in Slabs<sup>a</sup>  
[Btu/hr per linear foot of heated edge]**

Outdoor Design Temperature F	Heat Loss Per Foot of Exposed Edge, [Btu/hr.ft]		
	R=2.5 Vertical Extend- ing Down 18 in. Below Floor Surface	R=2.5 L-Type Extend- ing at Least 12 in. Deep and 12 in. Under	R = 5 L-Type Extend- ing at Least 12 in. Down and 12 in. Under
-20	105	100	85
-10	95	90	75
0	85	80	65
10	75	70	55
20	62	57	45

<sup>a</sup> Factors include loss downward through inner area of slab.



the loss from a basement wall is more complicated and the exact methods are beyond the scope of this manual. However, the loss can be estimated by determining the local winter ground temperature and using the formula in step #6. The results of this estimate will be higher than the actual heat loss for the basement, but the basement heat loss will make a very small contribution to the total heat loss.

8. Determine if the space for which the load is calculated has an infiltration or a ventilation load or both. If the space is mechanically ventilated by means of a fan bringing in outside air, then determine if there is positive pressurization of the building, that is, is there more outside air being pulled into the building than is exhausted or relieved? If this is the case, then infiltration will not be a problem. Any cracks or openings will serve to let air out of the space rather than in. In this case, the load is the ventilation air quantity. If the space is not pressurized at all or has negative pressurization, then the infiltration rate must be computed.

There are several methods for this calculation. The one which will be examined here is the air change method. Basically, this method consists of making an estimate of the infiltration quantity in air changes

per hour. One air change is the total volume of the space. Table A-4 shows values for air changes in various types of rooms. Certain adjustments should be made based on the tightness of construction, and the amount of traffic in rooms with exterior doors.

When an air quantity has been determined for infiltration or ventilation, the following formula may be used to calculate the heat loss:

$$\text{Heat Loss [BTU/Hr]} = \text{Air Quantity [Cubic Feet/Min]} \times \begin{matrix} \text{[Inside Temp - Air Temp]} \\ \text{[°F]} \end{matrix} \times 1.1 \text{ [BTU.min/Ft}^3 \text{ . Hr]}$$

**TABLE A-4**

**Air Changes Occurring Under Average Conditions  
Exclusive of Air Provided for Ventilation<sup>a</sup>**

Kind of Room	Number of Air Changes Per Hour
Rooms with no windows or exterior doors	0.5
Rooms with windows or exterior doors on one side	1
Rooms with windows or exterior doors on two sides	1.5
Rooms with windows or exterior doors on three sides	2
Entrance halls	2

<sup>a</sup>For rooms with weatherstripped windows or with storm sash, use two-thirds these values.

9. Total all calculated heat losses into a total heat loss. This number represents the heating load of the building.

In applying this method, there are several considerations which should be noted.

- a. Design heat loss is assumed to take place under steady state conditions. Under most circumstances, this is the middle of the night. For this reason, the temperatures to be used are the "97.5% temperatures." This means that for the average year, 2.5% of the hours during the winter months will be below this temperature. To design for more extreme temperatures will mean uneconomical oversizing of equipment. The notable exceptions to this are buildings in which the occupants cannot leave at will such as hospitals, or nursing homes, or buildings which will be used in emergencies such as churches or designated public buildings. For such buildings, a somewhat lower design temperature should be used.
- b. No credit should be taken for any internal heat gains which could offset heat loss.
- c. The total heat loss calculated does not represent the actual size of heating equipment but the output. Only after taking into account any efficiency losses should the equipment selections be made.

### Space Cooling (SC)

Calculations of the cooling load is considerably more complicated than the heating load. For this reason, only an outline of the procedure will be given here. The complete method can be found in Reference \_\_\_\_.

The components of the cooling load are:

- o External transmission load: Similar to the heating load, is heat conducted into the conditioned space from the outdoors.
- o Solar load: This is the direct solar gain through windows on other transparent surfaces.
- o Internal gains: These are heat gains from lights, people and equipment within the space.
- o Infiltration and ventilation load: Similar to heating load, these are heat gains from outdoor air entering the space.

The cooling load is calculated in the following manner:

A. External transmission load: This load is determined by the formula:

$$q = U \times A \times CLTD$$

where

q = heat gain

U = heat transmission coefficient

A = area of surface

CLTD = cooling load temperature difference

The CLTD is determined by the inside-outside temperature difference, the weight of the wall, roof, or window, the color of the external surface and the daily temperature range. The reason for this is that a heavy wall will cause a lag between the time of greatest heat on the outside of the wall and the time that the heat will reach the inside of the wall.

B. Solar load: This load is determined by the formula:

$$q = A \times SC \times SHGF \times CLF$$

where

A = net glass area

SC = shading coefficient determined by the type of glass and nature of internal and external shading.

SHGF = Solar heat gain factor for orientation of surface, latitude and month

CLF = cooling load factor representing the percentage of the instantaneous gain which shows up in the cooling load at a particular time.

C. Internal loads:

1. Lights -load is determined by:

$$q_s = 3.41 \times q_l \times F_u \times F_s \times CLF$$

where

$q_s$  = lighting load

3.41 = conversion factor for watts to BTU/HR

$q_l$  = light wattage

$F_u$  = fraction of total lights in use

$F_s$  = ballast allowance for fluorescent  
fixture

CLF = cooling load factor

2. People - load is determined by:

a). Sensible:

$$q_s = q_s/\text{person} \times \text{No. of people} \times \text{CLF}$$

where,

$q_s$  = sensible cooling load

$q_s/\text{person}$  = sensible gain for each person  
determined by activity

No. of people = number of people in the  
space at design hour

CLF = cooling load factor

b). Latent:

$$q_e = q_e/\text{person} \times \text{number of people}$$

where,

$q_e$  = latent gain per person determined by  
activity.

3. Equipment:

a). Sensible:

$$q_s = C_s \times 9 \times \text{CLF}$$

where,

$q_s$  = sensible cooling load from equipment

$q_r$  = manufacturers input rating in BTU/HR

$C_s$  = coefficient from Table A-5

CLF - cooling load factor

b). Latent:

$$q_l = C_l \times q_r$$

where:

$q_r$  = latent cooling load

$C_l$  = coefficient from table A-5

$q_r$  = manufacturer's input rating in BTU/HR

Coefficients for Appliances and Certain  
Laboratory Equipment

	$C_s$	$C_l$
<hr/>		
Hooded-Electric or steam heated	0.16	0.00
Hooded-Gas heated	0.10	0.00
Unhooded-Electric or steam heated	0.33	0.17
Unhooded-Gas heated	0.33	0.17

D. Infiltration and Ventilation:

1. Sensible:

$$q_s = 1.10 \times DT \times \text{SCFM}$$

where,

$q_s$  = sensible cooling load from outside air

1.10 = conversion factor (BTU/HR . SCFM)

DT = inside-outside temperature difference

SCFM = volume of outside air at standard  
conditions.

2. Latent:

$$q_e = 4840 \times W \times \text{SCFM}$$

where,

$q_e$  = latent cooling load from outside air

4840 = conversion factor (BTU/HR . SCFM)

SCFM = volume of air at standard conditions.

W=inside-outside humidity ratio difference in  
pound of water vapor per pound of dry air.

In order to calculate the cooling load, a time must be selected that is estimated to be the hour when the different loads peak. All of the different types of loads will have varying cooling load factors which determine when they will be "seen" by the coil. For a typical office building, the loads will build toward the end of the day. Loads may be calculated for 3, 4, and 5 o'clock with the highest total being the design hour.

Swimming Pool Heat (SWP)

Accurate thermal loads for swimming pools are not easily calculated by hand unless historical energy use data is available because the major heat loss from the pool is through the process of evaporation (roughly 1/2 to 2/3 of the load) and is highly dependent on local humidity and air movement. Because of this, SWP loads should be calculated using F-CHART, version 5 or a later edition.



There are numerous computer programs available for calculation of various thermal loads. These range from versions for hand-held, programmable calculators to main-frame computer codes such as BLAST or DOE-2. As stated previously, if a main-frame computer program is used for energy analysis of the structure then it shall also be used for calculation of loads for the solar system.

For projects that do not employ a main-frame computer program, it is suggested that designers consider using a microcomputer program that employs ASHRAE calculation techniques. One program that should be given serious consideration is F-LOAD, Version 5 or later edition.

F-LOAD is an interactive computer program for estimating heating/cooling loads and the energy used by equipment in supplying these loads. The methods used in the computations are based on those published by ASHRAE and NBS for calculating the design heating/cooling loads and for estimating seasonal equipment energy consumption. These methods also include the effects of thermostat turndown, night setback, passive solar heating (direct gain windows, and collector-storage walls) and other conservation measures. The program includes the capacity to do life-cycle cost analyses and first year cash flow analysis. The program is structured to allow the user to evaluate the energy and cost savings of various changes in heating/cooling equipment and in building construction or operation. The results

of the calculations can be printed out in any of several formats, depending on the degree of itemizations by walls, windows, or other parameters.

The users may also wish to consider using the F-CHART program for load calculation, especially for swimming pool systems.

F-LOAD and F-CHART are both available from the same authors and are, therefore, consistent in their approach.

## APPENDIX B

### ARRAY SIZING

There are numerous methods for sizing collector arrays for solar energy systems. It is not within the scope of this manual to discuss all of these methods or to list acceptable versus unacceptable procedures. Therefore, two methods are recommended for collector array sizing; the Solar Load Ratio (SLR) method as a hand calculation procedure and F-CHART, Version 5.1 or later edition, as a computerized method. One exception to the above procedures will be the use of main-frame, public domain, computer codes, such as BLAST or DOE-2, if these codes are used for calculating the thermal loads for the project.

The selection of the SLR and F-CHART methods is made because of their widespread use, general acceptance in the engineering community, applicability, and the extensive testing and verification work that has been done with these methods in the past. This selection does not represent a statement concerning the relative merits of other calculational procedures.

It is recommended that the system designer use the F-CHART computer program instead of the hand calculation method, if at all possible. Use of F-CHART will allow rapid comparisons and parametric studies to be made at very low cost. Also, as stated

In Appendix A - Load Calculations, design of a swimming pool system is best accomplished using F-CHART because of the complexity of heat loss calculation required.

### F-CHART

F-CHART is one of the most comprehensive and widely used simplified methods for solar system design. F-CHART was developed by the University of Wisconsin using the TRNSYS computer program to stimulate representative types of solar heating systems in several different geographical locations, using either air or water as the transport fluid. Correlations were determined between the monthly solar fraction and two dimensionless quantities that are particular to a given system being analyzed. One is a measure of the monthly solar radiation absorbed by the collector. The other is a measure of collector thermal energy losses. The result is a chart showing the solar fraction,  $f$ , as a function of these two dimensionless quantities.

Version 5.1 incorporates many enhancements to the earlier microcomputer versions of F-CHART. For collectors, Version 5.1 has the ability to analyze the performance of evacuated tubular collectors, CPC's, and one and two-axis tracking collectors. Considerable attention has been devoted to incidence angle modifiers for these collector types. Two new systems have been added. An active collection - passive storage system analyzes the performance of a solar system in which energy is stored in the building structure rather than in a separate storage unit. The pool heating system provides estimates of the energy loss

from a swimming pool, as well as the useful energy collected by the solar system. A cash flow analysis option has been added to the economics output.

In this version, it is possible for some parameters to have multiple values. For example, the collector orientation can be varied monthly and incidence angle modifiers can be entered from test data in 10 degree increments. A degree-day algorithm has been added to allow the degree-days to be estimated for any base temperature. F-CHART immediately checks most of the parameter values entered and indicates if they are out of range.

#### SLR Method

This is a parametric method based on hourly computer simulations for which correlations were developed using the ratio of available solar energy vs. monthly heating degree days. The difference between SLR and F-CHART is that F-CHART presents the basic solar collector characteristics as variables in the input parameters while SLR utilizes the performance of a reference system. This reference system is given in Table B-1 on the following page.

The SLR method is used by obtaining the LC (load collector ratio) for the desired solar fraction from Table B-1;

where,

$$LC = \frac{\text{Building load (BTU/F-day)}}{\text{Collection area (ft}^2\text{)}}$$

TABLE B-1

**Reference System**

Values of parameters used for the "standard" solar heating system that includes liquid-heating solar collectors, a heat exchanger, and water tank thermal storage. The values are normalized to 1 sq ft of collector (sq ft<sub>c</sub>).

Parameter	Nominal Value
<b>Solar Collector</b>	
1. Orientation	Due south
2. Tilt (from horizontal)	Lat + 10°
3. Number of glazings	1
4. Glass transmissivity (at normal incidence)	0.86 (6% absorption* 8% reflections)
5. Surface absorptance (solar)	0.98
6. Surface emittance (IR)	0.89
7. Coolant flow rate (mC <sub>p</sub> /sq ft <sub>c</sub> )	0.04 gpm water/sw ft <sub>c</sub> (20 Btu/hr-F-sq ft <sub>c</sub> )
8. Heat transfer coefficient to coolant (UA/sq ft <sub>c</sub> )	30 Btu/hr-F-sq ft <sub>c</sub>
9. Back insulation U-value (UA/sq ft <sub>c</sub> )	0.083 Btu/hr-F-sq ft <sub>c</sub>
10. Coolant heat capacity rate (mC <sub>p</sub> /sq ft <sub>c</sub> )	1 Btu/hr-F-sq ft <sub>c</sub>
<b>Collector Piping</b>	
11. Heat loss coefficient (UA/sq ft <sub>c</sub> )	0.04 Btu/hr-F-sq ft <sub>c</sub> (U = 0.3 Btu/hr-F = sq pipe or 1 in. insulation of k = 0.025 Btu/hr-ft-F)
<b>Heat Exchanger</b>	
12. Heat transfer coefficient (UA/sp ft <sub>c</sub> )	10 Btu/hr-F-sq ft <sub>c</sub>
<b>Thermal Storage</b>	
13. Heat capacity	1.8 gal water/sq ft <sub>c</sub> (15 Btu/F-sq ft <sub>c</sub> )
14. Heat loss coefficient (UA/sq ft <sub>c</sub> ), assuming all heat loss is to heated space	0 Btu/hr-F-sq ft <sub>c</sub>
<b>Controls</b>	
Building maintained at 70 F	
Collectors on when advantageous	

\* These values apply for normal incidence on ordinary double-strength glass (1/8 in.). For other angles of incidence, the Fresnel equation is used.

For any location listed in the table, the method consists simply of determining the heating load and the solar fraction desired.

The table results will, of course, be for the reference system. Since the generic system designed in this manual will be very close to, if not the same as the reference, this should present no problem. If however, the location desired is not in the table, the following procedure can be used to correct for a new location:

1. Obtain the following data.
  - a. Heating degree days (monthly)
  - b. Total solar radiation for a horizontal surface (monthly).

2. Adjust the horizontal radiation data for lat + 10° using:

$$\text{Incident radiation} = 1.0254 - 8200$$

where,

$$Y = \frac{\text{Monthly horizontal radiation}}{\cos(\text{latitude} - \text{solar declination at mid-month})}$$

$$\cos(\text{latitude} - \text{solar declination at mid-month})$$

$$\text{Solar declination} = 23.45^\circ \cos(30M - 187)$$

$$M = \text{Month number (1-12)}$$

3. Determine heating load (see Appendix A) in BTU/°F - day. This is determined by taking the total heat load in BTU/HR and using the following formula:

$$\text{Heat load (BTU/°F Day)} =$$

$$\frac{\text{Design heat load (BTU/HR)} \times (24 \text{ HR/Day})}{\text{Design temperature differences (F)}}$$

4. Determine the SLR for each month using:

$$\text{SLR} = \frac{\text{Collector area} \times \text{total radiation}}{\text{Heating load} \times \text{degree days}}$$

The SLR is a dimensionless number.

5. The annual heating fraction can then be determined by:

$$\text{Annual Solar Heating Fraction} = \frac{\text{Summation (M= 1, 12) } [\text{degree days (x)}]}{[\text{degree days}]}$$

where,

$$x = 1.06 - 1.366 (\exp)(-0.55 \text{ SLR}) + 0.306 \exp (-1.05 \text{ SLR})$$

(for  $\text{SLR} < 5.66$ )

$$\text{or, } x = 1$$

$$\text{(for } \text{SLR} \geq 5.66 \text{)}$$

This method has its limitations but is adequate for final design for small, envelope dominated buildings and for feasibility and preliminary design for other buildings.



## APPENDIX C

### WATER QUALITY ANALYSIS

The following analysis must be performed to determine if the quality of the water is sufficient to allow use of a direct recirculation system. Steps to be followed are:

1. Obtain a standard water chemistry report for the water to be used in the system. Results of this report shall include, as a minimum:

- o Dissolved total solids (DTS), mg/L
- o Calcium hardness, mg/L
- o M alkalinity, mg/L
- o pH

In most cases, this water chemistry report can be obtained from the local O & M Workforce Department. This report is used frequently in determining appropriate boiler feedwater treatment. If not, an analysis can be performed easily by most any local laboratory.

2. Using Table C-1, calculate the pH of saturation ( $\text{pH}_s$ ) of calcium carbonate ( $\text{CaCO}_3$ ) for the water using the following equation:

$$pH_s = 9.3 + A + B - (C+D)$$

where, from Table C-1,

A = value for range of DTS

B = factor for application temperature range, (normal system operating temperature)

C = factor for calcium hardness

D = factor for M alkalinity

The values for A, B, C, and D are dimensionless.

3. Using the results of step two above, and the pH of the water from step one, calculate the Ryznar Index (RI) using the following equation:

$$RI = 2(pH_s) - pH$$

4. Using Table C-2 and the calculated RI above, determine the tendency of the water in question for scaling and/or corrosion.

For direct use of the water in a solar system, the RI shall be in the range of 5.0 to 7.0. For water with a calculated RI outside of this range the designer may either choose another system type or require water treatment resulting in an RI in the acceptable range.

TABLE C-1

Data for Calculation of pH of Saturation (pHs) of Calcium Carbonate.

A		C		D	
Total Solids (mg/L)	A	Calcium Hardness (mg/L of $\text{CaCO}_3$ )	C	M Alkalinity (mg/L of $\text{CaCO}_3$ )	D
50-300	0.1	10- 11	0.6	10- 11	1.6
400-1000	0.2	12- 12	0.7	12- 13	1.0
		14- 17	0.8	14- 17	1.2
		18- 22	0.9	18- 22	1.3
		23- 27	1.0	23- 27	1.4
		28- 34	1.1	28- 35	1.5
		35- 43	1.2	36- 44	1.6
		44- 55	1.3	45- 55	1.7
		56- 69	1.4	56- 69	1.8
		70- 87	1.5	70- 88	1.9
		88- 110	1.6	89- 110	2.0
		111- 138	1.7	111- 139	2.1
		139- 174	1.8	140- 176	2.2
		175- 220	1.9	177- 220	2.3
		230- 270	2.0	230- 270	2.4
		280- 340	2.1	280- 350	2.5
		350- 430	2.2	360- 440	2.6
		440- 550	2.3	450- 550	2.7
		560- 690	2.4	560- 690	2.8
		700- 870	2.5	700- 880	2.9
		800-1000	2.6	890-1000	3.0

TABLE C-2

## Prediction of Water Tendencies by the Ryznar Index

Ryznar Index	Tendency of Water
4.0-5.0	Heavy scale
5.0-6.0	Light scale
6.0-7.0	Little scale or corrosion
7.0-7.5	Significant corrosion
7.5-9.0	Heavy corrosion
9.0 and higher	Intolerable corrosion

TABLE D-1

## PHYSICAL PROPERTIES OF WATER

Temperature of Water	Saturation Pressure	Specific Volume	Weight	
			Density	Pounds Per Gallon
Degrees Fahrenheit	Pounds per Square Inch Absolute	Cubic Feet Per Pound	Pounds Per Cubic Foot	Pounds Per Gallon
32	0.08859	0.016022	62.414	8.3436
40	0.12163	0.016019	62.426	8.3451
50	0.17796	0.016023	62.410	8.3430
60	0.25611	0.016033	62.371	8.3378
70	0.36292	0.016050	62.305	8.3290
80	0.50683	0.016072	62.220	8.3176
90	0.69813	0.016099	62.116	8.3037
100	0.94924	0.016130	61.996	8.2877
110	1.2750	0.016165	61.862	8.2698
120	1.6927	0.016204	61.7132	8.2498
130	2.2230	0.016247	61.550	8.2280
140	2.8892	0.016293	61.376	8.2048
150	3.7184	0.016343	61.188	8.1797
160	4.7414	0.016395	60.994	8.1537
170	5.9926	0.016451	60.787	8.1260
180	7.5110	0.016510	60.569	8.0969
190	9.340	0.016572	60.343	8.0667
200	11.526	0.016637	60.107	8.0351
210	14.123	0.016705	59.862	8.0024
212	14.696	0.016719	59.812	7.9957
220	17.186	0.016775	59.613	7.9690
240	24.968	0.016926	59.081	7.8979
260	35.427	0.017089	58.517	7.8226
280	49.200	0.017264	57.924	7.7433
300	67.005	0.01745	57.307	7.6608
350	134.604	0.01799	55.586	7.4308
400	247.259	0.01864	53.648	7.1717
450	422.55	0.01943	51.467	6.8801
500	680.86	0.02043	48.948	6.5433
550	1045.43	0.02176	45.956	6.1434
600	1543.2	0.02364	42.301	5.6548
650	2208.4	0.02674	37.397	4.9993
700	3094.3	0.03662	27.307	3.6505

Specific gravity of water at 60F = 1.00  
Weight per gallon is based on 7.48052 gallons per cubic foot.

TABLE D-2

## EQUIVALENTS OF PRESSURE AND HEAD

Pressure or Head	lb/in. <sup>2</sup>	lb/ft <sup>2</sup>	Atmos- pheres	kg/cm <sup>2</sup>	kg/m <sup>2</sup>	in. water (60F)	ft water (60F)	in. mercury (32F)	mm mercury (32F)
lb/in. <sup>2</sup>	1	144	0.068046	0.070307	703.067	27.707	2.3039	2.03601	51.7148
lb/ft <sup>2</sup>	0.0069445	1	0.000473	0.000488	4.88241	0.19241	0.01603	0.014139	0.35913
Atmospheres	14.696	2116.22	1	1.0332	10332.27	407.17	33.931	29.921	760.
kg/cm <sup>2</sup>	14.2234	2048.17	0.96784	1	10000.	394.08	32.840	28.959	735.559
kg/m <sup>2</sup>	0.001422	0.204817	0.0000968	0.0001	1	0.03941	0.003284	0.002896	0.073556
in. water	0.036092	5.1972	0.002456	0.00253	25.375	1	0.08333	0.073483	1.8665
ft. water	0.433103	62.3668	0.029471	0.03045	304.50	12.	1	0.88180	22.3980
in. mercury	0.491157	70.7266	0.033421	0.03453	345.316	13.608	1.1340	1	25.40005
mm mercury	0.0193368	2.78450	0.0013158	0.0013595	13.59509	0.535764	0.044647	0.03937	1

**TABLE D-3**

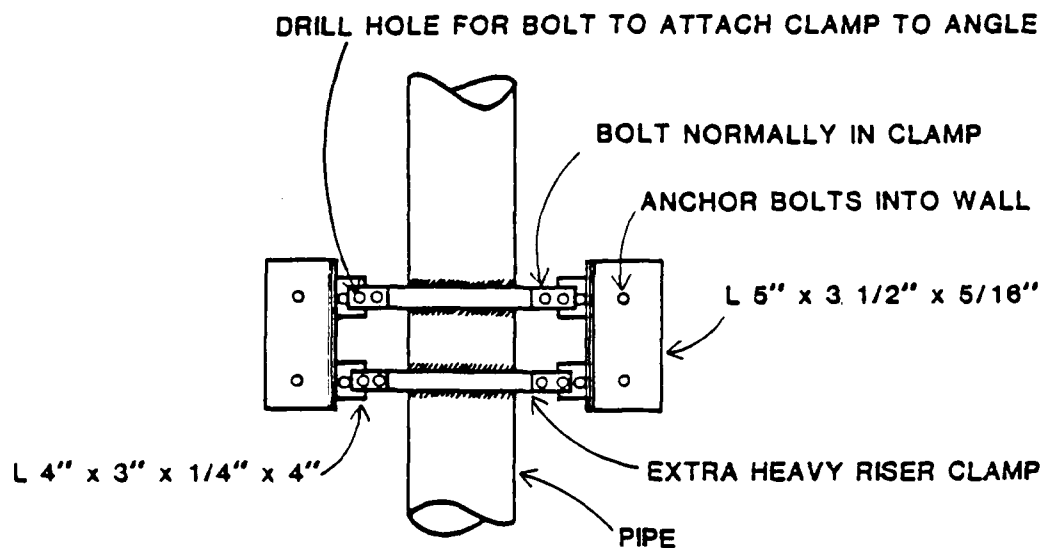
TYPE_K							
Nominal Dimensions, Inches				Calculated Values, Based on Nominal Dimensions			
Size, Inches	Outside Diameter	Inside Diameter	Wall Thickness	Gross Sectional Area of Bore, sq. Inches	External Surface, sq ft per lin ft	Internal Surface, sq ft per lin ft	Weight pounds per lin ft
1/2	.625	.527	.049	.218	.164	.138	0.344
5/8	.750	.652	.049	.334	.196	.171	0.418
3/4	.875	.745	.065	.436	.229	.195	0.641
1	1.125	.995	.065	.778	.294	.261	0.839
1 1/4	1.375	1.245	.065	1.22	.360	.326	1.04
1 1/2	1.625	1.481	.072	1.72	.425	.388	1.36
2	2.125	1.959	.083	3.01	.556	.513	2.06
2 1/2	2.625	2.435	.095	4.66	.687	.638	2.93
3	3.125	2.907	.109	6.64	.818	.761	4.00
3 1/2	3.625	3.385	.120	9.00	.949	.886	5.12
4	4.125	3.857	.134	11.7	1.08	1.01	6.51
5	5.125	4.805	.160	18.1	1.34	1.26	9.67
6	6.125	5.741	.192	25.9	1.60	1.50	13.9
8	8.125	7.583	.271	45.2	2.13	1.98	25.9

TYPE_J							
1/2	.625	.545	.040	.233	.164	.143	0.285
5/8	.750	.666	.042	.348	.196	.174	0.362
3/4	.875	.785	.045	.484	.229	.206	0.455
1	1.125	1.025	.050	.825	.294	.268	0.655
1 1/4	1.375	1.265	.055	1.26	.360	.331	0.884
1 1/2	1.625	1.505	.060	1.78	.425	.394	1.14
2	2.125	1.985	.070	3.09	.556	.520	1.75
2 1/2	2.625	2.465	.080	4.77	.687	.645	2.48
3	3.125	2.945	.090	6.81	.818	.771	3.33
3 1/2	3.625	3.425	.100	9.21	.949	.897	4.29
4	4.125	3.905	.110	12.0	1.08	1.02	5.38
5	5.125	4.875	.125	18.7	1.34	1.28	7.61
6	6.125	5.845	.140	26.8	1.60	1.53	10.2
8	8.125	7.725	.200	46.9	2.13	2.02	19.3

TABLE D-3  
PHYSICAL CHARACTERISTICS OF COPPER TUBE  
TYPES K, L, M

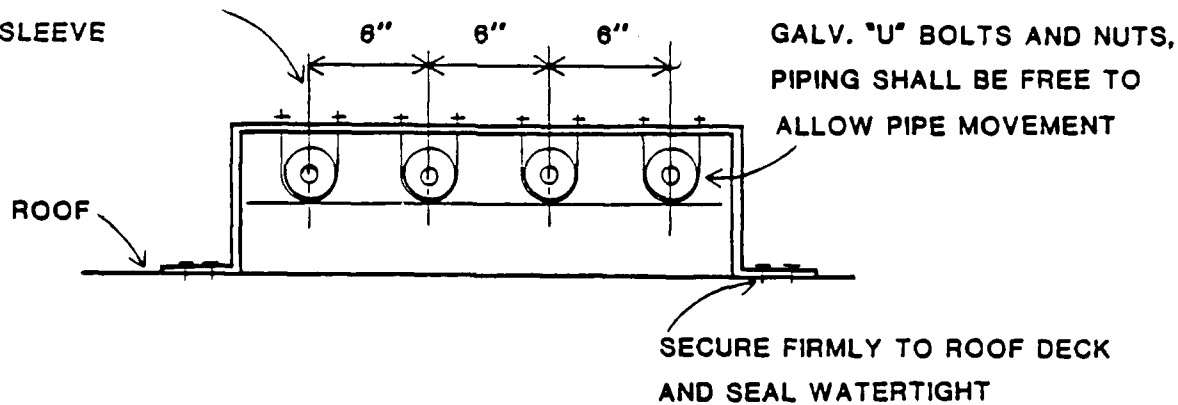
Nominal Dimensions, Inches				Calculated Values, Based on Nominal Dimensions			
Size, inches	Outside Diameter	Inside Diameter	Wall Thickness	Gross Sectional Area of Bore, sq. inches	External Surface, sq ft per lin ft	Internal Surface, sq ft per lin ft	Weight pounds per lin ft
3/4	.875	.811	.032	.517	.229	.212	0.328
1	1.125	1.055	.035	.874	.294	.276	0.465
1 1/4	1.375	1.291	.042	1.31	.360	.338	0.682
1 1/2	1.625	1.527	.049	1.83	.425	.400	0.940
2	2.125	2.009	.058	3.17	.556	.526	1.46
2 1/2	2.625	2.495	.065	4.89	.687	.653	2.03
3	3.125	2.981	.072	6.98	.818	.780	2.68
3 1/2	3.625	3.459	.083	9.40	.949	.906	3.58
4	4.125	3.935	.095	12.2	1.08	1.03	4.66
5	5.125	4.907	.109	18.9	1.34	1.28	6.66
6	6.125	5.881	.122	27.2	1.60	1.54	8.92
8	8.125	7.785	.170	47.6	2.13	2.04	16.5





### VERTICAL PIPE SUPPORT

PIPING TO BE INSULATED AND SHALL  
BE WRAPPED WITH 18 GA. STEEL SADDLE  
12" LONG SLEEVE



### HORIZONTAL PIPE SUPPORT

FIG. D-1 - ADDITIONAL PIPING SUPPORT DETAIL

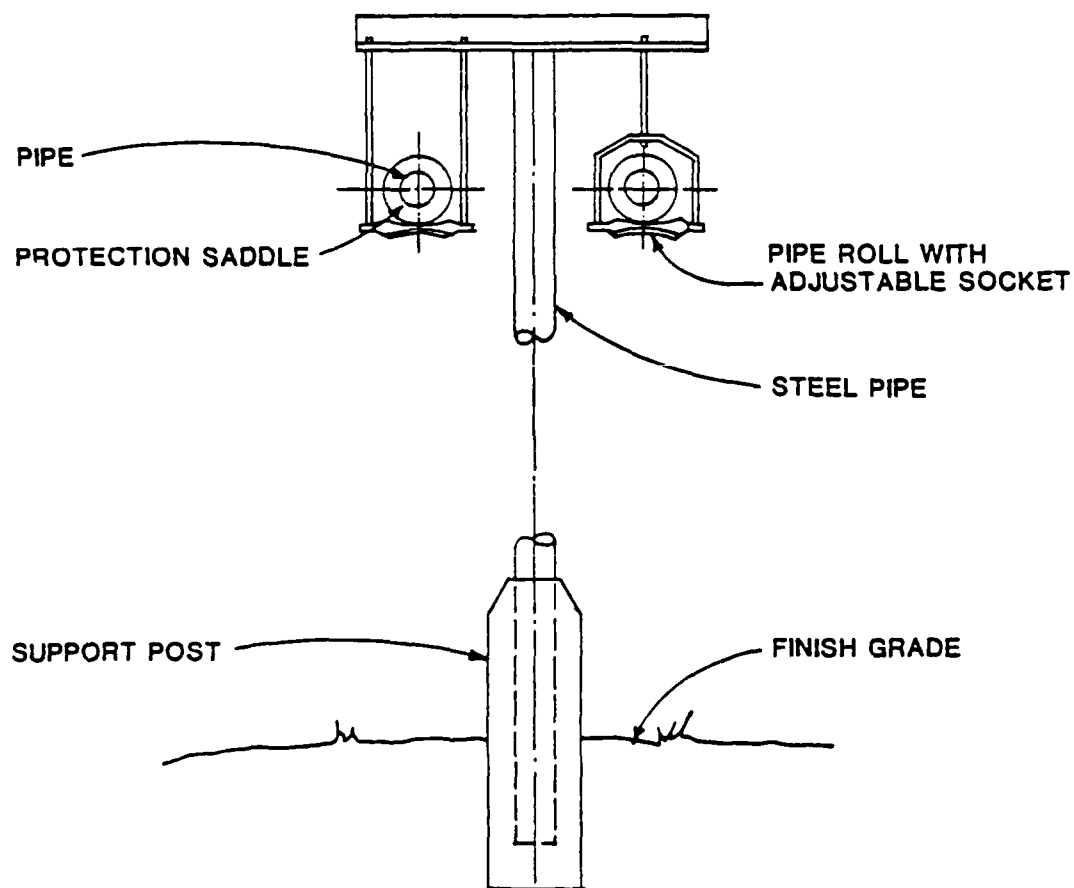
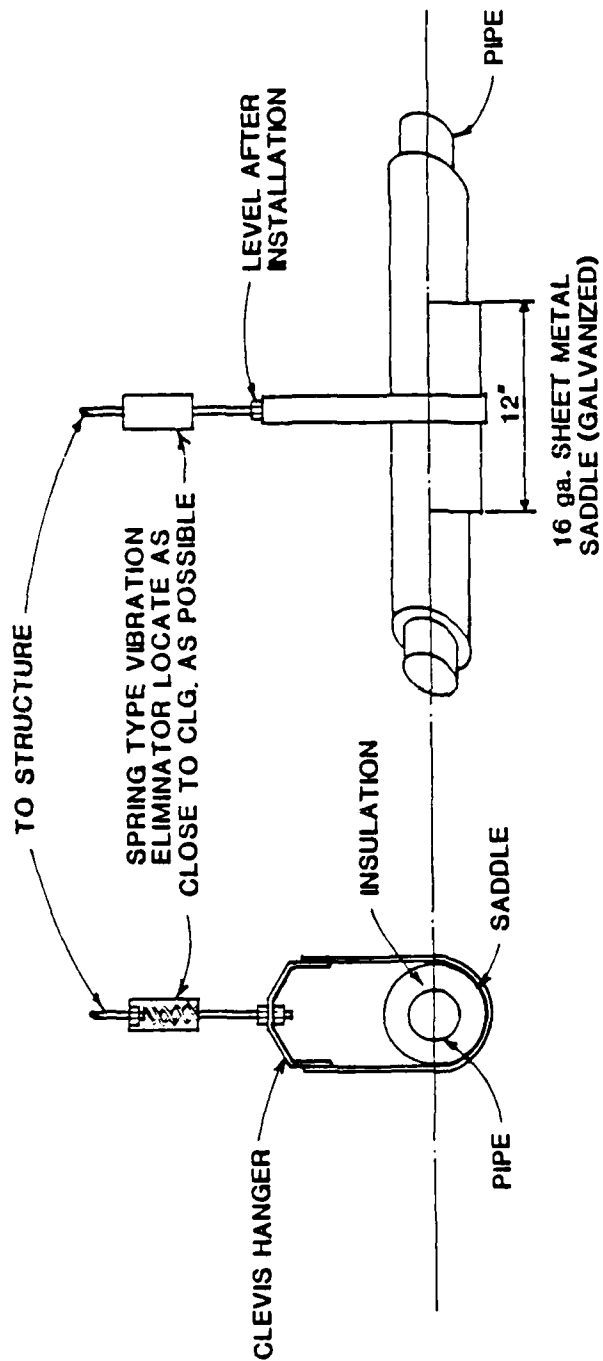


FIG. D-2 - TYPICAL ABOVE GRADE PIPE SUPPORTS



NOTE: CONDENSER WATER PIPES NEAR CHILLER SHALL BE HUNG WITH VIBRATION ELIMINATOR PIPE HANGERS AS DETAILED. INSERT A STRIP OF FELT BETWEEN CLEVIS HANGER AND PIPE.

**FIG. D-3 - PIPE HANGER DETAIL**

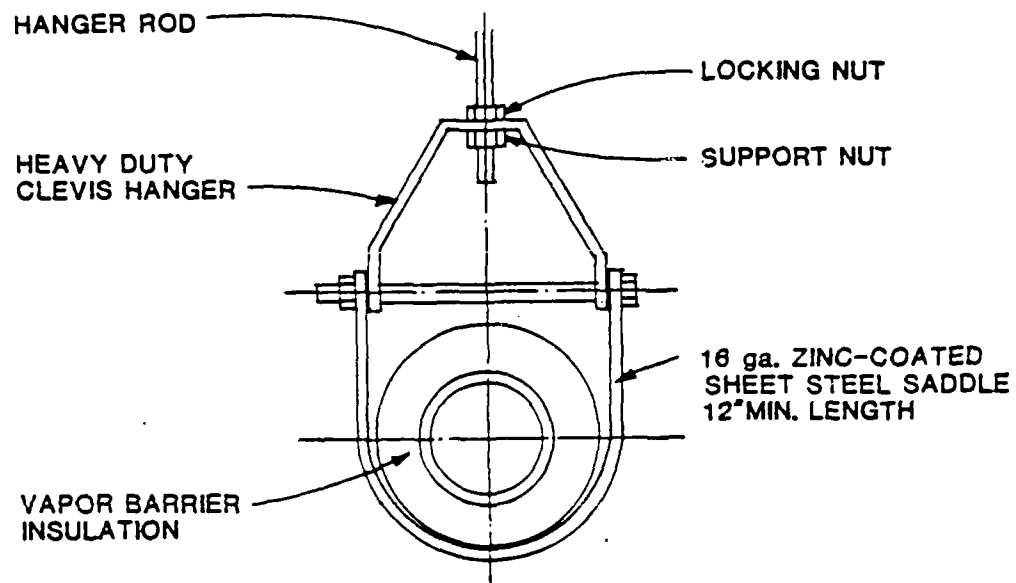


FIG. D-4 - PIPE SUPPORT - CLEVIS HANGER

END

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